MIDLAND RADIO
AND TELEVISION
SCHOOLS
INC.

POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 4

TRANSMITTER CIRCUIT COMPONENTS

LESSON NO. 1

WHO ARE WE

.....To say it is impossible.

The past thirty years has produced so many amazing scientific developments that more and more people are fast coming to the conclusion that practically nothing is impossible.

We can well remember the day when it was said that the automobile industry would never become very large because the use of the automobile was limited to improved city streets. Never a thought was given to the fact that some day concrete highways would span our nation from coast to coast and border to gulf, and that the automobile industry would become one of our industrial mainstays.

Then, too, we well remember the time shortly after the advent of the first tri-motor airplane, when it was stated that planes larger than 15 passengers would be impractical.....that when you passed certain limitations, the efficiency of the aircraft would be curtailed. Many people also claimed that speeds in excess of 200 miles per hour would be impossible as the aircraft would be subjected to such a great amount of friction with the air that it would become extremely hot....so hot as to be destroyed. Yet today, planes capable of carrying nearly 100 passengers in excess of 200 miles per hour are a reality.

Then came a day when radio was subjected to criticism. 'Radio will never be of any great importance because of the 'frying' noise produced by radio receivers that makes it unpleasant to listen to the programs.' Those so-called 'frying' noises of old have been eliminated, and today, as you know, the radio industry is one of the most important in our nation.

When we stop to think that practically every new development has been subjected to early criticisms.....when we stop to realize the amazing accomplishments of men.....who are we to say that certain things are impossible. We know nothing of what the future will bring.

You are preparing yourself now for a future development in the field of Radio. The harder you study, the stronger fortified you will be in your chosen profession.

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Unit Four

COMMERCIAL BROADCAST STATION OPERATION

"This unit comprises ten interesting lessons devoted to the operation of a commercial broadcast station. In these lessons, we shall give sufficient information pertaining to the design, layout, maintenance, and operation of a broadcast station so that you will be qualified to fill the position of an operator as soon as you obtain your government license. An operator should be familiar with many facts, devices, and practices in addition to the theoretical knowledge gained from the lessons in Unit 3.

"The first three lessons in this unit are devoted largely to the study of material that is entirely new to you. Then starting with lesson four, we shall begin describing the layout and the equipment used in the control room of a broadcast station.

"The later lessons in this unit describe commercial transmitters. Nearly all stations use factory-built transmitters, generally RCA, Western Electric, or Collins. Since it is very likely that the student will secure employment at a broadcast station which uses one of these transmitters, we are including general descriptions and complete instructions on the tuning, operation, and maintenance procedures. Complete wiring diagrams are also given on the latest 100/250, 1,000, and 5,000 watt transmitters. These may appear complicated at first, but after you study them several times, you will be able to understand the reason for the relay circuits, protective devices, auxiliary equipment, etc., that are shown thereon.

"I advise that you spend many hours studying the commercial transmitter circuits. They represent the equipment with which you will actually be working in your chosen profession. The better you know your equipment, the more valuable you are to your employer."

Lesson One

TRANSMITTER CIRCUIT COMPONENTS

"A broadcast transmitter represents a considerable investment to the station owner. To protect the tubes and various circuits of the transmitter from excessive current surges and to make certain that the voltages are applied to the tubes in the proper order, a system of relays is used. These are the power control circuits which are described in this lesson. It is very necessary that any prospective radio operator be thoroughly familiar with the fundamentals of this important subject.

"In addition, this lesson describes the principles of frequency monitors and modulation monitors. These two instruments must be used in every broadcast station according to the ruling of the Federal Communications Commission."

1. TRANSMITTING INDUCTANCES. In every broadcast transmitter, there are found many inductances whose values may range from a few microhenries to several henries. These will include the coils having comparatively large inductances, such as the modulation choke, the windings of the various audio transformers, and the chokes in the power-supply filter system; and those of lesser inductance, such as radio-frequency chokes, tuning inductances, and stray inductances due to leads and connecting wires. Of most interest, perhaps, is the design of the inductances forming the various tank circuits.

To be highly efficient, a tank circuit should contain a minimum of resistance. Most of the resistance in the tank circuit will be the inherent resistance of the tank inductance itself. It is, of course, physically impossible to design any inductance that does not contain some resistance. The resistance is unwanted since it dissipates power and thus causes the overall efficiency of the transmitter to be lowered. At best, the only solution is to minimize the resistance of the tuning inductances as much as possible.

In an earlier lesson, the definition of the factor Q was given. At that time, it was seen that the Q of a circuit or of a capacitor or an inductor is the reactance of the element divided by its resistance. This ratio of reactance to resistance should be as large as possible so that the losses will be a minimum. Thus, high-Q coils are most desirable.

The resistance of a conductor varies inversely as the square of its diameter, and it would, therefore, seem to be advantageous to use conductors having relatively large cross-sections in the manufacture of the tuning inductances. There is, however, another factor which must be considered. As is well known, the resistance of a conductor to a radio frequency current is generally much greater than the DC resistance of the same conductor. This apparent increase in resistance is due to the phenomenon of skin effect. Skin effect causes the current to be concentrated in certain parts of the conductor and leaves the remainder to contribute little or nothing toward carrying the current. This results from the fact that the magnetic flux which surrounds the conductor cuts through the conductor itself and induces voltages which tend to oppose the current flow. Naturally, the center of the conductor will be cut by more magnetic lines than is its surface, and this makes the opposing effect maximum at the conductor's center. At radio frequencies, this phenomenon is sufficiently great to affect seriously the flow

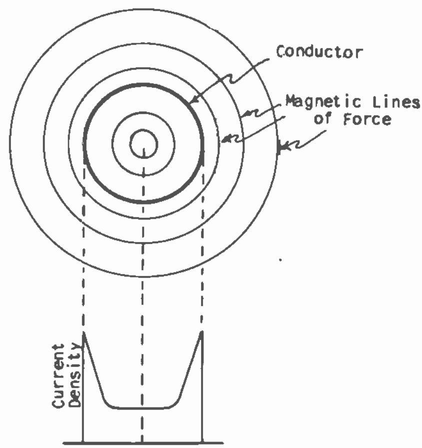


Fig. 1 Illustrating how the current density varies throughout the cross-sectional area of an isolated round conductor.

of current, most of which flows along the surface of the conductor where the impedance is low, rather than near the center where the impedance is high. Fig. 1 illustrates an isolated round conductor, and gives the current density for different parts of the conductor's cross-section. Note from this diagram that the current density is highest for parts of the conductor encircled by the fewest flux lines. The ratio of the effective alternating current resistance to the direct current resistance of the conductor increases with frequency, with the conductivity of the conductor material, and with the size of the conductor.

This same principle also governs the current distribution in the conductors of a coil. However, skin effect in coils is much more complicated and greater in magnitude than in isolated conductors. This is due to the fact that each turn of the coil produces flux that causes skin effect in adjacent turns. As a result, the radio frequency resistance of coils may be as much as several hundred times their resistance to direct current.

Now again considering the Q of a coil, we must realize that although this factor is the ratio of the coil's reactance to its resistance, the actual resistance of the coil at radio frequencies will be many times its DC resistance and, in addition, this resistance includes any dielectric losses which the coil may have.

The actual value of the Q of a coil depends primarily on its construction and is determined by many complicated factors for which a complete mathematical analysis has never been made. There are, however, certain general principles that can be used as a guide in the design of coils. When coils differing only in wire diameter are compared, it is found that for each frequency, there will be a particular size of wire that will produce the highest Q. This optimum size of wire is different for different frequencies and is often, although not always, the largest wire that can be wound in the space available. Unless the wire is too small, changes in wire size have surprisingly little effect on the AC resistance, because the increased skin effect of the larger conductors offset to a great extent the greater cross section.

When the inductance, proportion of length to diameter, and direct current resistance of a coil are kept constant, it is found that increasing the dimensions of the coil itself tends to reduce the AC resistance and hence yields a greater Q. In addition, the larger coil provides a winding space for larger wire than the smaller coil, which, if utilized, will further tend to increase the Q as the dimensions are increased. A coil of large size can utilize a large conductor to better advantage than one of small size, since the increased space over which the flux is distributed reduces the flux density in the vicinity of the conductor and hence lowers the skin effect to reasonable values, even with large wires.

It has been determined that the best shape for a coil with a given inductance is neither a very long coil with a small diameter, nor a short coil with a large diameter, but rather, one of intermediate proportions. In fact, the best proportion for a coil is a length approximately equal to its diameter. This is not always convenient, but does produce the least loss, all factors considered. Copper tubing and copper strip conductors are used in transmitter coils since the tank circuits of high powered stages carry considerable radio frequency current.

Other factors which affect the Q and thereby the efficiency of a transmitting inductance, include the material and sizes of various objects which may be within the immediate electrostatic and electromagnetic fields of the coil. Any piece of metal within the magnetic field of the coil will have radio frequency voltages induced within it. If this metallic object is of such a shape that circulating R.F. currents are set up by the induced voltages, these currents will dissipate power which must be supplied by the tank circuit. The effect is the same as though a resistance had been added in series with the tank coil and the efficiency of the tuning inductance is thereby reduced. If possible, the distance between the coil and any shielding or metallic objects should be at least equal to the diameter of the coil itself.

It is, of course, not possible to isolate a coil completely. Ordinarily it is mounted on stand off insulators and, in addition, there are various other non-conductors or insulators in the electrostatic field of the coil. When the dielectric field of the coil is changing rapidly, the electrons in these various insulating bodies are strained backward and forward. It may so happen that these insulators have high dielectric losses; that is, exhibit a large amount of dielectric hysteresis. If this is the case, the molecular friction set up by the to and fro motion of the electrons will generate heat and dissipate power, all of which must be supplied by the tank circuit. Again, the effect is the same as though a resistance had been added directly in series with the coil. Some insulators are much worse in this respect than others. A given material may have very high insulating qualities and yet contribute considerable loss when used in a transmitting stage. Much research has been done on this particular problem and the outcome has been several new materials having remarkably low dielectric losses.

Some use is being made at present of radically different types of inductances and tuned circuits to obtain very low losses in transmitters. One means of achieving low losses is to employ tuned circuits utilizing resonant transmission lines. This is especially true of ultra-high frequency transmitters where the losses would otherwise be very great.

Mention has been made in previous lessons that high powered stages often use inductive rather than capacitive tuning. Very high voltages are employed and variable condensers able to withstand these high voltages would be large and cumbersome. For this reason, fixed condensers are often employed and tuning is accomplished by varying the inductance of the tank circuit. Rough inductance changes are made by using more or less turns of the tank coil. Fine adjustment of the inductance is accomplished by varying the position of a copper flipper placed within the tank coil. This flipper is so arranged that its plane may be made parallel to the axis of the coil, or at right angles to it. The amount of voltage induced into this flipper is therefore controlled by varying its position. This, in turn, changes the amount of current in the flipper and varies the effect which the flipper has on the inductance of the tank. Using a tuning flipper does, of course, tend to increase the losses of the coil somewhat, because some resistance, as well as capacitive reactance, is reflected from the flipper into the tank coil. By careful design, however, loss due to this source is minimized and the advantages of the system outweigh the disadvantages.

2. **TRANSMITTING CONDENSERS.** Every transmitter utilizes many condensers whose capacities vary throughout a wide range. There must be filter condensers, R.F. by-pass condensers, and tuning condensers. Although electrolytic condensers may be found in low-voltage power-supply filters such as used in bias power packs, they cannot be employed in very high voltage rectifier filter systems, since they are not able to withstand the high voltages involved. Instead, paper condensers and condensers using transformer oil as

a dielectric are usually found. Naturally, they are very large and bulky in size, because the dielectric must be thick enough to withstand several thousand volts. Making the dielectric thick, however, reduces the capacity of the condenser and so the surface area of its plates must be increased accordingly. As a result, the capacity of most filter condensers is not larger than two mfds., since even this value has comparatively large dimensions.

R.F. by-pass condensers ordinarily have mica dielectric, since this material has a high dielectric strength (is able to withstand large voltages) and has low dielectric losses. All condensers have some losses, but those using air for the dielectric have a minimum. All the losses exhibited by a condenser are usually represented by a certain hypothetical series resistance, which would dissipate the same amount of power that is lost in the condenser itself. For example, assume that a certain condenser when drawing a current of 2 amperes has a total power loss due to all causes of 5 watts. This hypothetical series resistance would have such a value that when 2 amperes of current flow through it, 5 watts of power would be dissipated. Its value is found as follows:

$$P = I^2 \times R$$

or, rearranging

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

By substituting in this formula, we find:

$$R = \frac{5}{2^2}$$

$$= \frac{5}{4}$$

$$= 1.25 \text{ ohms.}$$

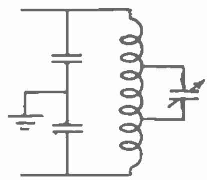
Thus, this condenser is equivalent to one having no losses connected in series with a resistance of 1.25 ohms.

A condenser having no losses; that is, containing no resistance, would have a power factor of 0. In this case, the current flowing through the condenser would lead the applied voltage by exactly 90°. Naturally, no condenser is this perfect. The quality of a dielectric in regard to its freedom from losses is usually expressed decimally as the power factor that this dielectric would produce. For example, one particular grade of mica has a power factor of .019. The smaller the power factor of a dielectric, the lower will be the losses that it will set up. Some grades of paper, for example, have power factors of approximately .024, indicating that they will have greater losses than will mica. Furthermore, the power factor is not constant, but increases with frequency. This is due to the fact that the loss occasioned by dielectric hysteresis becomes greater the faster the rate of change of the current.

Naturally, the amount of power dissipated in a condenser increases as the current flowing through it becomes larger. For this reason, all R.F. by-pass condensers have current ratings as well as voltage ratings. The amount of current that may flow safely depends upon several factors. For a given capacity, a larger current may flow at a high frequency than at a low frequency. For example, a certain condenser rated at .0001 mfd. and having a maximum voltage rating of 5,000 volts, will pass safely .1 ampere at 100 kc., .3 ampere at 300 kc., 1 ampere at 1,000 kc., or 2 amperes at 3,000 kc. This condenser would naturally have a lower capacitive reactance the higher the frequency and a larger current could flow through it before the voltage dropped across the condenser would reach the limiting value. On the other hand, the losses of the condenser increase somewhat with frequency, which tends to prevent the allowable current from increasing in direct proportion to the frequency increase.

Tuning condensers, for the most part, have air dielectrics and are very similar to variable condensers used in receiving circuits. Ordinarily, they are more rigidly constructed, the plates are made of a thicker material, the frame is heavier, and the insulating parts are of higher quality. The plates are usually highly polished as a rough surface allows the accumulation of more dust than one which is perfectly smooth. There are no sharp corners or edges on the plates of transmitting condensers, since a sharp point will produce a corona loss at a lower voltage than will a rounded corner. Corona losses are present only at very high voltages. They consist of a partial ionization of the air adjacent to the condenser plate. This phenomenon is manifested by a blue haze about the condenser plate and a crackling sound which may or may not be present. It constitutes a large power loss and is to be prevented at all costs.

Fig.2 One method of tuning a tank circuit which does not require a variable condenser having a high voltage breakdown.



As mentioned before, high powered transmitting stages usually employ fixed capacitors, and the tuning is accomplished by varying the amount of inductance in the circuit. Another way of effecting the same result is to use fixed capacitors as shown in Fig. 2, and then employ a small tuning condenser connected across a small part of the tank coil. By this method, the total capacity needed may be secured and yet the condensers employed are not cumbersome and do not require much room. There will not be much voltage across the small tuning condenser and it may be used to secure fine adjustments of the tuning.

The spacing between the plates of the condenser will, of course, depend upon the voltages to which the condenser will be subjected.

The following table gives the average condenser spacing for various operating voltages.

ACTUAL AIR GAP IN INCHES BETWEEN ROTOR AND STATOR PLATES	PEAK FLASH-OVER VOLTAGE
.070 Inch	3,000 Volts
.084 "	4,000 "
.100 "	4,250 "
.168 "	5,200 "
.171 "	5,250 "
.200 "	5,800 "
.230 "	6,300 "
.294 "	7,250 "
.500 "	12,000 "

3. RATINGS OF POWER TUBES. As has been mentioned in previous lessons, power tubes are rated by their manufacturers according to their ability to dissipate power. Thus, a 100-watt tube is one which can dissipate safely 100 watts of power at its plate without causing either the plate or the glass walls of the tube to reach temperatures so high as to cause damage.

In addition to this rating given to tubes by their manufacturers, the Federal Communications Commission has designated certain tubes for certain amounts of power output. According to the Commission, the maximum rated carrier power of a broadcast transmitter is the same as the sum of the power ratings of all the vacuum tubes in the last radio stage. The power rating of a vacuum tube is determined, of course, by its design and class of operation or system of modulation. A tube capable of dissipating 100 watts of power could produce an output power of 150 watts when operating at an efficiency of 60%, or only 43 watts when operating at an efficiency of 30%. The efficiency at which the tube will be operated depends upon the total amount of power involved and whether high or low level modulation is employed.

The tables on pages 8 and 9 list the approved power ratings of vacuum tubes for operation in the last radio stage of broadcast transmitters under various conditions.

4. RELAYS USED IN TRANSMITTERS. For the protection of the transmitter itself, and for the safety of the operating personnel, every broadcast transmitter employs a number of relays. There is an overload relay whose purpose is to cut off high voltages whenever the plate current of a stage becomes excessive, thus preventing damage to the tube; a time delay relay whose purpose is to delay the application of the high voltage to the plates of tubes until the filaments have reached their operating temperature; and various other relays whose purposes are to make certain that the circuits are closed in the proper order. Most transmitters, for example, incorporate a relay whose purpose is to prevent the application of plate voltage to a stage until it is certain that the bias voltage has been applied. In fact, relays form a most important adjunct to any modern transmitter.

In general, all relays of the type used in transmitters, consist of three essential parts: (A) The coil assembly, which may

F.C.C. POWER RATINGS OF COMMON TRANSMITTING TUBES

Power Rating of Vacuum Tubes for High-Level Modulation or Plate Modulation in the Last Radio Stage

Power Rating (watts)	Amperex	Collins	De Forest	Eitel McCullough	Federal Telegraph	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	United Electronics	Western Electric
50				50-T						211-D 211-E 248-A 276-A
75	HF-100 203-A 211 838 852 860	C-203A C-211	503-A 511 552 560		F-303-A F-311-A F-352-A		203-A 211 852 860	203-A 211 838 850 852 860	303-A 311 361-A 938 952	242-A 242-B 242-C 260-A 261-A 284-A 295-A
100					F-102-A F-108-A					
125	HF-200 203-H 211-C 211-D 211-H 805	C-200 C-201 C-211D		150-T				803 805	905	
250	204-A HF-300	C-204A C-300	504-A 561 571		F-204-A F-212-E F-331-A	354	204-A 212-D 831 861	204-A 831 861	304-A 312-E	212-D 212-E
350	849		549	300-T	F-100-A F-349-A		849	849	949	270-A
500						255				251-A
750	851		551	500-T	F-351-A		851	851	951	279-A
1000					F-346-A	1554	846	846		
2500			520-B 520-M		F-328-A F-3652-A	3054	820-B	1652		228-A
5000			507 548 563		F-307-A F-320-A F-320-B F-348-A F-363-A		207 848 863	207 848 863 891 892		220-B
10,000					F-101-B F-110-A F-110-X F-116-A F-332-A F-332-B F-332-C F-358-A			858		232-A 232-B
40,000								862		298-A

(Courtesy Radio, Limited)

F.C.C. POWER RATINGS OF COMMON TRANSMITTING TUBES

Power Rating of Vacuum Tubes for Low-Level Modulation or Last Radio Stage Operating as Linear Power Amplifier

Power Rating (watts)	Amperex	Collins	De Forest	Eitel McCullough	Federal Telegraph	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	United Electronics	Western Electric
25								203-A		
50	HF-200 203-H 211-H			150-T		354		803		242-B 242-C
75	HF-300 212-E		504-A		F-304-A F-312-A		204-A 212-D	204-A	304-A 312-E	212-D 212-E
125			549	300-T	F-100-A F-349-A		849	849	949	270-A
250			551	500-T	F-351-A	255 1554	851	851	951	251-A
500					F-346-A	3054	846	846		279-A
1000			520-B 520-M		F-328-A F-3652-A		820-B	1652		228-A
2500			507 569		F-307-A F-320-A F-320-B F-363-A		207 863	207 863 892		220-B
5000					F-358-A			858		
8500					F-101-B F-110-A F-110-X F-116-A F-332-A F-332-B F-332-C					232-A 232-B
25,000								862 898		298-A

Power Rating of Vacuum Tubes for Grid Bias Modulation in the Last Radio Stage

Power Rating (watts)	Amperex	Collins	De Forest	Eitel McCullough	Federal Telegraph	Heintz & Kaufman	Hygrade Sylvania	RCA Mfg. Co.	United Electronics	Western Electric
50						354				212-E 270-A
100				300-T						
125				500-T		255				
250						1554				
500						3054				
2500					F-307-A					

(Courtesy Radio, Limited)

contain one or several windings, and whose purpose is the establishing of the magnetic flux. (B) The core which provides a magnetic circuit of variable and relatively low reluctance, a portion of which is subjected to physical motion. (C) The contact assembly which is actuated by the armature.

The operation of any relay involves the opening or closing of one or more circuits through the use of contacts which are made to separate or come together when the armature or clamper is moved. The opening or closing of the contacts results from the motion of the armature whose position, in turn, depends upon the opposing forces set up by the magnetic flux surrounding the electromagnet and the spring tension or gravitational pull provided in the relay. To insure satisfactory operation of the relay, it is necessary that the open and closed position of the armature be definite and positive in action. In most relays, this requirement is fulfilled by providing a large, leakage flux when the armature is open. The armature and its mounting form parts of the magnetic circuit. When the current through the coil increases, the flux increases and for some critical value, the armature closes. This action reduces the reluctance of the magnetic circuit so that the armature is held tightly and the contacts are not likely to be affected by vibration.

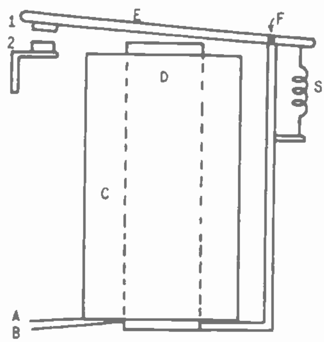


Fig.3 An outline drawing of a simple type of relay.

Fig. 3 illustrates diagrammatically a very simple type of relay. C is the coil, and A and B are the connecting leads to the coil. D is the core of the coil and E is the armature which is pivoted at point F. S is a spring which tends to hold the contacts 1 and 2 apart. When the attraction of the core D for the armature E becomes great enough to overcome the pull of the spring S, the armature is pulled downward, closing the contacts 1 and 2. It is evident that when the armature is in the down position, and the contacts 1 and 2 are closed, the reluctance of the magnetic circuit is very low, since there is no air gap provided. Reducing the reluctance in this manner naturally increases the magnetic flux and the armature is held tightly against the core, thus insuring a firm pressure between the contacts 1 and 2.

When the current flowing through the coil of the electromagnet is DC, there is no tendency for the relay to chatter or vibrate.

On the other hand, allowing an alternating current to actuate the electromagnet tends to cause the armature to chatter since the attractive force of the core for the armature will vary directly with the instantaneous values of the alternating current. This action is eliminated in properly designed relays by designing them so that they are somewhat sluggish in action. The speed of operation is determined largely by the degree in which eddy currents are permitted to flow in conductors which are within the magnetic field of the electromagnet. It is well known that induced eddy currents act in such a direction as to oppose a change in the existing flux. Thus, the flux established by the eddy currents effectively reduces that set up by the electromagnet. As a result, any system which reduces the eddy currents established in the magnetic field in the relay will aid in increasing the speed of operation. On the other hand, slow operation, or operation from alternating current is obtained by allowing a relatively large amount of eddy current losses.

By building up the core of the relay from a bundle of fine iron wires, eddy currents are reduced to a minimum and a quick acting relay results. Relays for use with alternating currents often have a copper sleeve between the iron core and the coil winding, whose purpose is to provide a relatively large amount of eddy current losses. When so designed, the relay is slow acting and chattering of the armature is prevented.

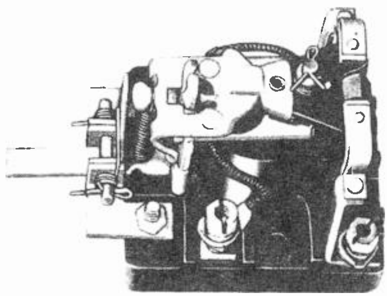


Fig.4A A keying relay.

Since relays are available in so many different designs for as many different applications, the following points should be considered when it is necessary to select a relay for a given purpose: first, the close and release currents required for operating the relay; second, the permissible voltage drop across the relay coil; third, the rise in temperature of the coil under the conditions of use which will be encountered in practice; fourth, the resistance of the coil; fifth, the voltage above ground at which the relay is to be operated; sixth, the purpose the relay is to serve; and seventh, the current-carrying capacity of the contacts.

It should be realized that in ordinary stock models the currents at which the relay opens and closes are not usually specified. This is due to the fact that throughout the life of the relay, these

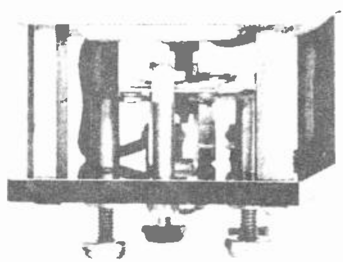


Fig.4B A dash pot time delay relay.

opening and closing currents are subject to wide variation. An accumulation of dust, dirt, or other gummy substances, the weakening of the spring tension, and improper maintenance, all contribute toward making the opening and closing currents somewhat variable throughout the relay's life. For this reason, if it is necessary that the relay open and close upon definite current values, this fact should be emphasized when ordering the relay. Several types of relays are illustrated in Fig. 4. The one at A is a small keying relay; B is a time delay relay; and C is a general-purpose four-pole, double-throw relay.

A type of relay often found in transmitters is the so-called solenoid plunger type. The principle upon which it operates may be seen from an inspection of Fig. 5. A soft-iron plunger (P) fits

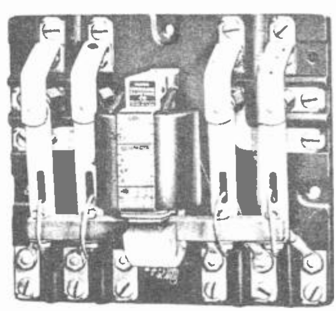


Fig.4C A general purpose relay.

loosely into the center of a coil. When no current is passing through the coil, the plunger falls by gravity to approximately the position indicated in this figure. Stops are provided to prevent the plunger from falling out of the coil entirely. As current is passed through the coil, the magnetic field created by this current tends to follow the path of least reluctance, which is through the

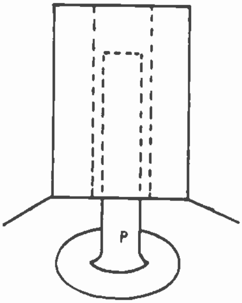


Fig.5 Illustrating the construction of the solenoid plunger type of relay.

soft iron plunger. Since the magnetic lines of force tend to shorten their length, they exert a force on the plunger attempting to pull it upward until it is completely within the core of the coil. When the current passing through the coil is large enough so that the magnetic field is able to overcome the pull of gravity, the plunger moves upward and by various lever arrangements can be made to open or close contacts.

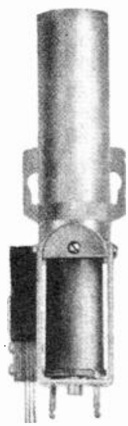


Fig.6 An oil dash pot time delay relay.

If it is desired to allow a definite time to elapse before the plunger moves to the end of its stroke, its bottom end is connected to a piston which moves through a cylinder containing a small quantity of oil. This piston has small holes drilled in it to allow the leakage of oil from one of its faces to the other. As current flows through the coil of the time delay relay, the plunger attempts to move upward and, in so doing, pulls the piston. The oil being somewhat heavy, requires a definite time to leak through the face of the piston, and by proper design, the closing of the relay may be delayed as long as several minutes.

This same type of relay is often used as an overload relay in transmitters. In that case, however, its action must be instantaneous and if the plunger and piston arrangement is used, the cylinder in which the piston moves is not filled with oil. If only a small

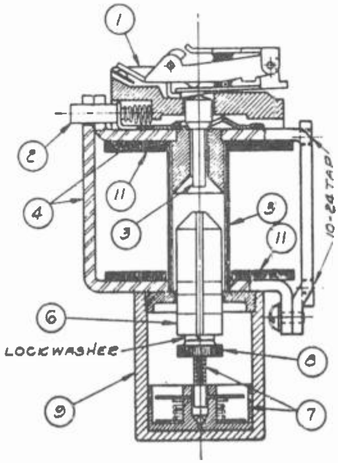


Fig.7 Constructional diagram showing the various parts of a dash pot time delay relay.

delay is required, the cylinder may be made practically air tight and the delay is provided by air rushing from one side of the piston to the other. These relays are also known as "dash-pot" relays. An illustration of an oil filled dash-pot relay is given in Fig. 6. The internal construction of a dash-pot time delay relay is illustrated in Fig. 7.

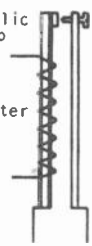


Fig.8 Showing the principle of the thermo-electric type of time delay relay.

Another type of time delay relay that is often found in transmitters is the so-called thermal type. It depends for its operation upon the heating of a bimetallic thermo-element, and therefore operates on the same principle as an ordinary thermostat. A bimetallic element consists of two thin strips of metal soldered together. One strip is composed of a metal which expands considerably as its temperature is raised. The other strip is made from a metal whose size changes but little with changes in temperature.

If heat is applied to a strip made by welding these two different metals together, the strip will be bent away from the metal whose size is affected most by heat. One metal of the bimetallic strip is usually invar, a metal whose expansion is very small. The other half of the bimetallic strip may be made of brass or some other common metal. Fig. 8 illustrates how a bimetallic element operates. At ordinary temperatures, the brass and invar are of equal length and the composite strip is in a straight position. The application of heat, however, causes the brass to expand more than the invar and the strip is bent, thereby closing contacts 1 and 2.

Heat is applied to the bimetallic element by using it as a form on which to place a wire-wound resistor. When current is sent through the resistor, an appreciable amount of heat is produced which causes the warping or bending of the element itself. In commercial

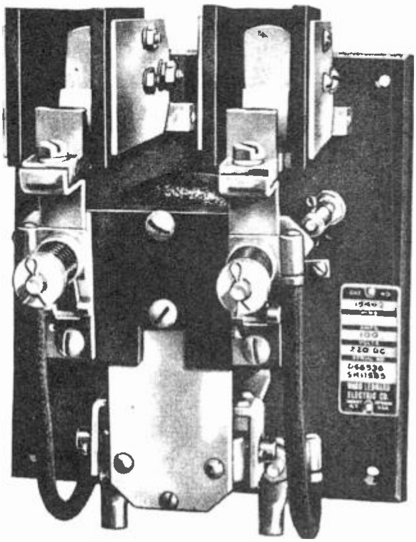


Fig.9 A large power relay whose contacts are capable of carrying 100 amperes.

models, the closing of a thermo-element contact operates another relay which in turn applies power to the circuit which has been delayed. It will require from 10 seconds to 1 minute for the thermo-element to bend sufficiently to close its contacts. The delay period is controlled by adjusting the distance between the contacts for which a screw is usually provided.

It should be realized that there are in general two types of relays classified according to the purpose they serve. These two types are power relays and control relays. Power relays are for the purpose of closing circuits containing a considerable amount of power. For example, the closing of any circuit containing the primary of a transformer, either filament or plate, necessitates the use of a power relay. Power relays, as such, must have contacts capable of carrying a comparatively large amount of current. In addition, the contacts must be so designed that there will not be an excessive amount of arcing which would cause corrosion of the contact surfaces. On the other hand, a control relay ordinarily does not close any power circuits of the transmitter, but serves merely to complete a circuit of a power relay or another control relay. All switching of any importance is done by means of relays. In fact, only the main disconnect switch is operated manually, and this switch is touched but rarely. Thus, to start or stop the transmitter, a button is pushed or a small toggle switch is thrown, and this action, in turn, operates a series of relays which place the transmitter on the air, or remove all power from the transmitter. A power relay whose contacts have a current-carrying capacity of 100 amperes is shown in Fig. 9.

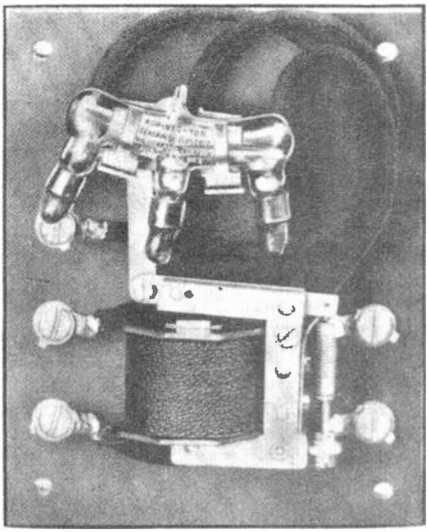


Fig.10 A relay with mercury contacts.

When a relay is required to break a large amount of current, it may employ mercury contacts. These consist of a glass tube of mercury having contacts fused into the glass. When the current through the coil of the relay reaches a certain value, the armature is attracted and by a lever arrangement the tube of mercury is tilted so that the mercury falls into the lower end thus closing the contacts. A relay of this type is illustrated in Fig. 10. Relays are not ordinarily used to break direct current, since this causes a large amount of sparking at the contacts.

It is possible to reduce the arcing and sparking at the contacts of a relay by using contact surfaces which have been rounded so as not to present sharp edges and corners from which an electric discharge may easily take place. Small contacts such as used in telephone relays may have a greater curvature than those used to break a considerable amount of power. A contact which is not required to carry much current does not need a large surface area. In closing, it is desirable that the contacts approach one another with a sliding, rolling, or rotary motion, rather than butting together, for by this action, the contacts tend to be self-cleaning. It is necessary that the contacts, having closed, be maintained in intimate contact by a definite pressure. This pressure is ordinarily provided by the pull on the armature when the relay coil is energized, although in some cases "snap action" through the use of springs or specially designed switches serves the same purpose. The circuit which the contacts open and close, the voltage, current, frequency, and number of makes and breaks per unit of time, all determine the necessary contact area as well as the material from which the contacts are made. Thus, it is not possible to specify what contact area will be necessary for carrying a given current, except in more or less general and arbitrary terms. Often, when the current to be controlled is less than 1 ampere, the telephone type of contacts will suffice, especially if the circuit is non-inductive. Usually, however, when the current to be broken is greater than a quarter of an ampere, large metal or carbon contacts are employed. The resistance of the carbon is in some cases objectionable, since it causes an appreciable voltage drop to exist across the contacts. For currents up to about 25 amperes, mercury contacts are used. They are very reliable and require but little maintenance.

The successful operation of any relay device depends upon the contacts being maintained in good condition. It is essential that the contacts be cleaned periodically. Assuming that the relay equipment has been properly designed, installed, and maintained, a periodic cleaning of the contacts by rubbing their surfaces with a sheet of tough bond paper should suffice. Never, except in most unusual cases, clean the contact faces with abrasive pastes or powders. Furthermore, the use of files, emery cloth or sandpaper is not to be recommended. Such measures may result in the accumulation of particles of sand, emery, or metals on the faces of the contacts. Magnetic particles are particularly undesirable, since the contacts are usually in a fairly strong magnetic field, and magnetic particles are difficult to remove. Another point indicating that abrasives should not be employed is the fact that the curvature of the contact surfaces may be changed with a resulting change in the current density, which may cause excessive sparking or heating of the contacts. Sometimes small burnishers are employed to remove the corrosion from the contacts. They are of such a nature that they will not injure the metallic faces.

5. POWER CONTROL CIRCUITS. The relays and their circuits which control the application of power to a transmitter and safeguard it from overloads may be very simple, consisting of only two relays, or may, as in some commercial transmitters, employ many relays connected in intricate circuits.

Fig. 11 shows a diagram of a very simple time delay relay. S-1 is the starting switch. When this switch is closed, a circuit is completed through to the primaries of the various filament transformers, and all the tubes in the transmitter begin to heat. A circuit is also completed through the heating element of the thermal relay and through contacts 3 and 4 which are closed as long as the relay coil W_1 is not energized. The bimetallic element begins to heat and after a period of half a minute or so, it bends enough to close the contacts 1 and 2. This completes a circuit through the winding of the relay W_1 and this relay is energized. The actuating of this relay closes contacts 4 and 5 and opens contacts 3 and 4. With contacts 4 and 5 closed, the energizing current for this relay is now supplied directly through these contacts and the energizing current does not have to pass through contacts 1 and 2. Furthermore, the opening of contacts 3 and 4 opens the circuit through the heating element and the bimetallic strip begins to cool. This, of course, causes contacts 1 and 2 to open. In addition, the closing of contacts 4 and 5 completes the circuit through the primary of the plate transformer of the rectifier, which, of course, applies plate voltages to the tubes in the transmitter.

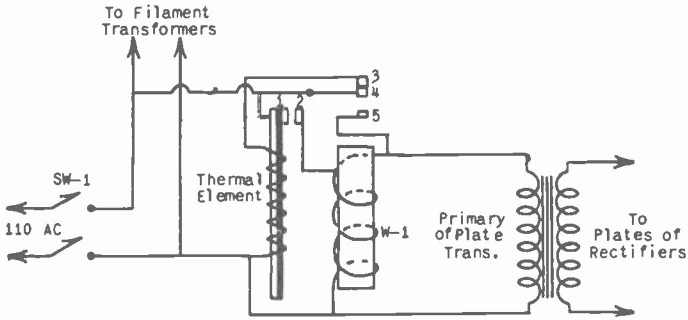


Fig.11 A simple time delay relay using a bimetallic strip.

An interruption of the line voltage or the opening of the starting switch S_1 will de-energize relay W_1, opening contacts 4 and 5 and before power can again be applied to the plates of the rectifier tube, the thermal element will have to function once more. In this way, the rectifier tubes are protected, since it is impossible to apply plate voltage to them until the filament voltage has had sufficient time to allow the filaments to reach their operating temperature.

One disadvantage of this circuit is the fact that the current drawn by the primary of the plate transformer must flow through the contacts bimetallic elements 1 and 2 for an instant before relay W_1 is energized. There is little possibility that this current will damage these contacts, still it is advisable to provide additional relay contacts to take care of this emergency. Thus, most time delay relay circuits of this type have an extra contact and the circuit appears as shown in Fig. 12. In this circuit, current cannot flow through the primary of the plate transformer until the time delay relay has closed its contacts 6 and 7. This prevents a current surge through contacts 1 and 2 of the thermal element. Except for the addition of these two extra contacts, the circuit is the same as the one shown in Fig. 11.

The types of relays illustrated in Figs. 11 and 12 are used to some extent in amateur transmitters, but are not employed in broadcast transmitters. This is due to the fact that they are not recycling. Let us see what this term means. Consider Fig. 11. As soon as the contacts 1 and 2 of the bimetallic element close, relay W-1 is energized and the transmitter is on the air. Now, if the starting switch SW-1 is opened at once, relay W-1 will be de-energized and the transmitter will be off the air. An immediate reclosing of the starting switch will cause relay W-1 to be re-energized and the transmitter will again be on the air; that is, there will be no time delay, since the bimetallic element will not

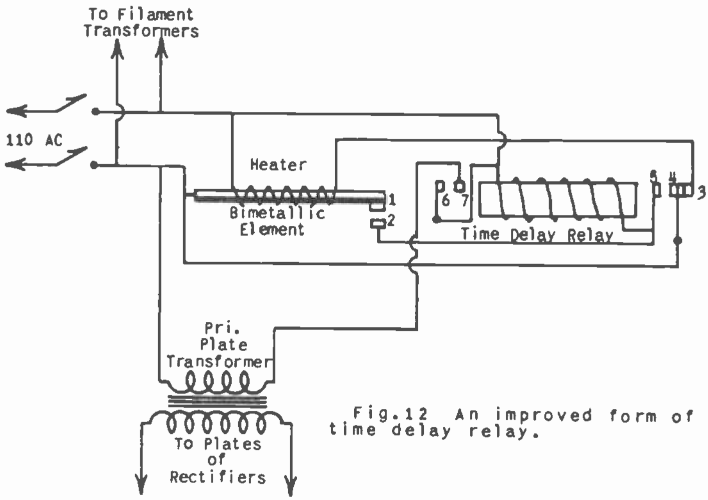


Fig.12 An improved form of time delay relay.

have had time to cool. Thus, if the starting switch is opened and closed rapidly enough, the plate voltage will be applied to the mercury vapor rectifier tubes each time that the switch is closed. This is undesirable, because the filaments of mercury vapor tubes cool rapidly, and the application of plate voltage to these tubes at the same time that the filament voltage is applied is liable to be injurious to them. Naturally, it is not to be expected that anyone will play with the starting switch in this manner, but to make the transmitter foolproof, and to avoid any possibility of this occurring, a recycling type of time delay relay is employed.

A relay circuit of this type is illustrated in Fig. 13. Its operation is as follows: When the starting switch SW-1 is closed, current flows through the heater winding of the bimetallic element, and through the break contact 3 of the relay W-1 back to the other side of the line. When the bimetallic element has had time to heat, it makes contact 1 and breaks contact 2. When contact 1 has been made, a circuit is now complete from one side of the line through the winding of relay W-1, through the bimetallic element, and through the contact 1 to the other side of the line. This energizes relay W-1 and causes it to break contact 3 and make contacts 4 and 5. The making of contact 4 completes a circuit from one side of the line, through the winding of relay W-1, and through contact 4 to the other side of the line. This allows relay W-1 to remain energized even after the thermal element has cooled. The opening of contact 3 will open the circuit of the heater of the bimetallic element and it will begin to cool. As soon as this element has cooled sufficiently to make contact 2, a circuit will be completed from one side of the line through the winding of relay W-2, through contact 5 of relay W-1, through contact 2 of the bimetallic element, through the bimetallic element, and through the contact 4 of relay W-1 back to the other side of the line. This energizes relay W-2, and closes contacts 6 and 7. The closing of contact 6 provides a

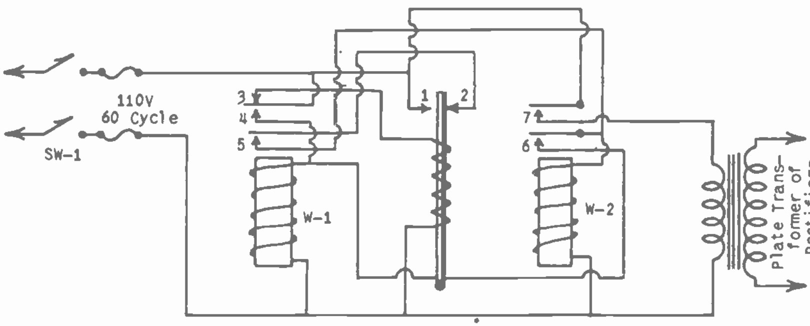


Fig.13 A time delay relay with immediate recycling.

circuit from one side of the line through the winding of relay W-2, through contact 6, and through contact 4 of relay W-1 and back to the other side of the line. This keeps the energizing current of W-2 from flowing through the contact 2 of the bimetallic element. The closing of contact 7 completes the circuit from one side of the line through the primary of the plate transformer of the rectifier tubes, and through contact 7 back to the other side of the line, thereby placing the transmitter on the air.

That this relay circuit is recycling should now be evident. If the starting switch is opened and then closed as soon as the transmitter goes on the air, plate voltage would not be applied to the mercury vapor rectifier tubes until the bimetallic element has had time to heat and cool again; that is, the relay circuit would have to recycle or to complete its sequence of operations once more.

Most time delay relays of the dash pot type are recycling. The plunger is pulled up into the solenoid slowly, since a certain amount of time must elapse before the oil or air can rush from one side of the piston to the other. However, when the solenoid is deenergized, the plunger drops almost instantaneously, since a mechanical arrangement allows the oil to pass quickly from one side of the piston to the other when the piston is moving downward. Therefore, when the starting switch is opened, the plunger drops quickly, and reclosing the starting switch causes the relay to begin its cycle. In this manner, the mercury vapor tubes are protected from premature application of the plate voltage.

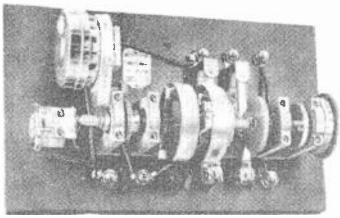


Fig.14 A motor driven time delay relay.

A newer type of time delay relay which has recently gained much favor consists of a small synchronous motor similar to the motors used in electric clocks. When the starting switch is closed, a magnet causes several gears to become engaged, and the motor which also starts immediately drives cams through the gear train. By using gears which reduce the speed of the motor, the cams may be made to turn very slowly. After the time interval is completed, one of the cams closes a contact which applies power to the delayed circuit, and another cam opens the circuit to the motor, the holding magnet remains energized thus keeping the timed circuit closed

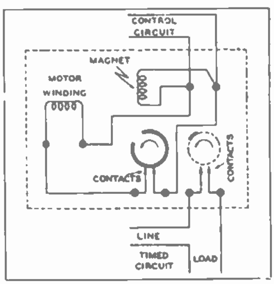


Fig.15 A simplified circuit diagram of the motor driven time delay relay illustrated in Fig. 14.

until the starting switch is opened. Opening the starting switch de-energizes the holding magnet, disconnects the gears from the motor, and allows the cams to return immediately to their starting position. Thus, this circuit has immediate recycling, and full protection is provided. A photograph of a motor driven time delay relay is shown in Fig. 14, A simplified diagram of its circuit appears in Fig. 15. The amount of time delay is adjusted by turning the knob at the right of the shaft; a graduated scale is provided so that the delay interval may be set for any value from 5 to 100 seconds.

Perhaps one of the most important relays in a transmitter is the overload relay. It is this relay which protects the tubes from damage in case they draw excessive plate current. Often this relay is of the dash pot type, but does not have an appreciable time delay. A very slight time delay is desirable so that a modulation surge of very short duration will not cause the overload relay to operate and thus take the transmitter off the air. Sometimes, the overload relay returns to its normal position when the overload has passed, and sometimes it has a holding winding which keeps the relay energized until it is reset by pushing a button which opens the circuit of the holding winding. In certain types, the overload contacts have a spring which would normally keep them apart. The action of the spring is overcome by a trigger arrangement, and when an overload occurs, the trigger is sprung and the spring pulls the contacts apart. Often, an insulated shaft is provided so that the trigger arrangement may be reset after the relay has tripped.

In some of the larger transmitters, an automatic reset is provided in the overload relay. When an overload occurs, the overload relay removes the high voltage and then re-applies it after a delay of 1 or 2 seconds. If the overload is still present, the relay trips again, and again after a small delay, it applies the plate voltage. If the overload occurs for the third time, the overload relay remains tripped and must be reset manually.

One other relay which must be used on transmitters employing water-cooled tubes is the flow-indicator relay. This is a combination of a meter to indicate the rate of water flow through the cooling jackets and a relay which disconnects all the voltages from the water-cooled tubes in case the rate of flow falls to too low a value or is interrupted. In addition, a dial type of thermometer provided with relay contacts is employed so that the temperature of the water may be read and so that all voltages may be removed from the water-cooled tubes in the event that the water temperature becomes excessive.

We will now describe the operation of the various relays in one of Western Electric's 1,000 - watt transmitters. This transmitter consists of a 100-watt exciter unit followed by a 1,000-watt power amplifier stage. Each unit has its own set of relays for protecting the transmitter. There are in all 12 relays arranged in the somewhat complicated circuit shown in Fig. 16. The power supplied to this transmitter is 3 - phase 220-volts, 60 - cycles. The main switch in this transmitter is the one marked SW-1. It is normally left closed, since the transmitter will not begin to function until the starting switch SW-2 is also closed. Notice that the connections to the crystal heater are taken off ahead of the main power switch. The crystal heater operates twenty-four hours a day without interruption. This is necessary since opening the heater circuit during the time the station is off the air would change the temperature of the oven enough that frequency stability could not be maintained. When the starting switch SW-2 is closed, the line voltage appears across the voltage regulator T-1. This is merely

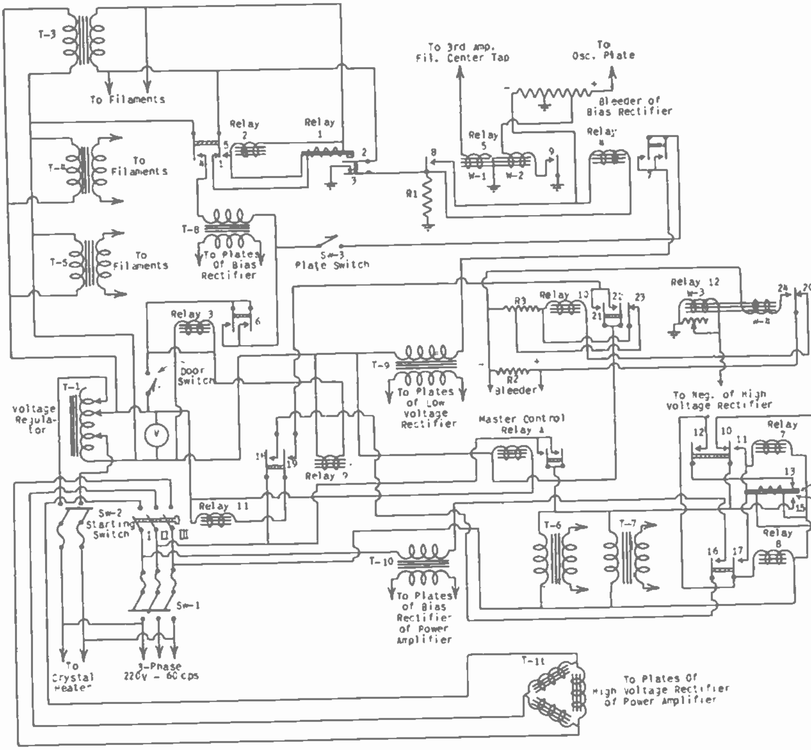


Fig.16 The power control circuit of one of Western Electric's 1000-watt transmitters.

an auto transformer whose purpose is to compensate for line voltage variation. A voltmeter V is connected across the secondary of this auto transformer and the voltage regulator should be so adjusted that the meter reads 220 volts at all times.

There is now supplied an alternating voltage to the primaries of transformers T-3, T-4, and T-5. These transformers provide filament voltage for all of the tubes in the exciter unit including the rectifier filaments. In addition, a path is now completed through relay 3, relay 9 and the power amplifier, master control relay A. Relay 3 and relay 9 are door-switch relays and will not operate unless all of the doors of the entire transmitter are closed and locked. The closing of the master control relay A in the amplifier unit supplies filament voltage for the amplifier tubes, the bias rectifier tubes, and the high-voltage rectifiers.

Across the secondary of the transformer T-3, there is connected the heating element of the time delay relay 1. This path is completed through the break contact 1 of relay 2. The heating of the thermal element causes it to bend, and after a definite delay interval, contact 2 is made, while contact 3 is broken. The making of contact 2 completes a circuit through relay 2, the energizing of which closes contacts 4 and 5 and opens contact 1. The opening of contact 1 breaks the circuit through the heating element and allows it to cool. The making of contact 5 provides a holding circuit for relay 2 and allows it to remain energized, even after the thermal element has cooled. When contact 4 of relay 2 has closed, a circuit is now completed through the primary of T-8 through contact 6 of relay 3 (which is energized if the doors are closed) back to the other side of the line. Thus, plate voltage is applied to the bias rectifier power pack in the exciter unit.

At the top center of this drawing, there is shown the bleeder of the bias supply rectifier. From the negative terminal of this bleeder resistor, there is now a path through relay 4 back to contact 3 of relay 1. By this time, the thermal element has cooled sufficiently to allow contact 3 to be made again and since contact 3 is grounded, the voltage between the negative end of the bleeder resistor and ground forces a current through relay 4, causing it to pull over contact 7.

With the closing of contact 7 on relay 4, the line voltage is applied to the primary of the transformer T-9, which provides voltage for the plates of the low-voltage rectifier contained in the exciter unit. This rectifier supplies plate voltage for the 100-watt stage of the exciter unit and the amplifier preceding it. The oscillator plate voltage and buffer plate voltage are derived from the bias power supply in this unit. The exciter unit is now in complete operation. The only relay remaining in this unit yet to be explained is No. 5, which is the overload relay. It consists of two windings, W-1 and W-2. One terminal of W-1 is grounded and the other connects to the filament center tap of the 100-watt stage. Thus, all of the current drawn by this stage flows through this winding. Should this current become excessive for some reason, this relay will close contacts 8 and 9, which has the following result. The closing of contact 8 shorts out the winding of relay 4, and opens contact 7. This opens the circuit supplying high voltage to the plate power supply rectifier, and thus removes plate voltage from the 100-watt unit. The closing of contact 9 completes a path for the winding W-2 of relay 5. This winding derives its voltage from a portion of the bleeder in the bias supply rectifier. Thus, even after the overload has passed (it may be instantaneons produced by a modulation peak), contacts 8 and 9 still remain closed and prevent the application of the high voltage to the 100-watt stage. To reset the overload relay, a push button, not shown, is connected in series with the winding W-2 of relay 5. Pushing this button opens the circuit of W-2, allows contacts 8 and 9 to open, and re-establishes plate voltage in the exciter unit.

We are now ready to consider the operation of the relays in the power amplifier unit. The master control relay A and the door switch relay 9 have already closed, having been operated when the starting switch was thrown. All of the filaments in the amplifier unit are heating and the closing of the master control relay A applied the voltage to the heater windings of relay 6, which is the time delay relay of this unit. This heater winding completes the circuit through the break contact 10 of relay 7. Since it may be a little difficult to trace this circuit, its path will now be described. Current flows from phase II just above the main power switch through the contacts of the master control relay A to the break contact 10 of relay 7, through the heater winding of the thermal unit, and back to phase III of the 3-phase line. This causes the bimetallic strip to heat and after a definite delay interval, contacts 14 and 15 are closed. When this occurs, a circuit is completed through the winding of relay 7, which closes contacts 11 and 12 and opens contact 10. The closing of contact 11 provides a holding circuit for relay 7, whereas the opening of contact 10 opens the circuit through the heater winding of the thermal element, and allows the bimetallic strip to cool.

Again, after a definite delay interval, the bimetallic element will cool sufficiently to make again contacts 13 and 14. This completes a circuit through the winding of relay 8 as follows: Current flows from phase II through the contacts of the master control relay A, through contacts 11 of relay 7, which are now closed, through the bimetallic element and contacts 13 and 14, through contacts 12 of relay 7 and through the winding of relay 8 back to phase III of the line. The energizing of relay 8 closes contacts 16 and 17 which has the following effect: The closing of contact 17 allows the current which is energizing relay 8 to flow from phase II through the contacts of the master control relay A, through the contacts 11 of relay 7, through contact 17 of relay 8 and back to the third phase of the line. Thus, the current energizing relay 8 does not have to flow through the bimetallic element. The closing of contact 16 completes the following circuit. Current may now flow from phase I through the primary of the transformer T-10, which supplies plate power for the bias rectifier supply in the amplifier unit, through contact 16 of relay 8, through contact 18 of relay 9 (the door-switch relay) and back to phase II of the line. This action causes the bias power supply to begin to function and very shortly thereafter, a voltage appears across the resistor R2, which is the bleeder of this power supply. The winding of relay 10 is connected across the bleeder on the bias rectifier through the break contact 20 of relay 12. Thus, when the bias voltage appears across the bleeder resistor R2, relay 10 is actuated, closing contacts 21 and 22 and opening contact 23. The purpose of contact 23 is to short out a part of a series resistor R3 so that sufficient current may flow through the winding of relay 10 to energize it. It will, of course, require less current through this winding to hold these contacts in place after they have once been thrown and the opening of contact 23 removes the short from a part of this series resistor, thereby reducing the current through the winding of relay 10. When contacts 21 and 22 of this relay are closed, a circuit is completed which energizes relay 11. The path of the energizing current is from one side of the voltage regulator through the winding of relay 11 to contact 19 of relay 9 (the door-switch relay), through contacts 21 and 22 of relay 10, and back to the other side of the secondary of the voltage regulator. Naturally, this path will not be complete unless all door switches are closed, which will allow relay 9 to be operated and will close contact 19.

Relay 11 is a large solenoid contactor which when energized draws over three contactors to close the three phase alternating current supply to the high voltage transformer T-11. This results in the supplying of an alternating voltage of high value to the plates of the main power amplifier mercury-vapor rectifier tubes, where it is then rectified to the desired direct current potential of 3,000 volts for the plate supply.

All voltages have now been applied and the entire transmitter is in complete operation. The remaining relay to be described is No. 12, which is the overload relay of the power amplifier unit.

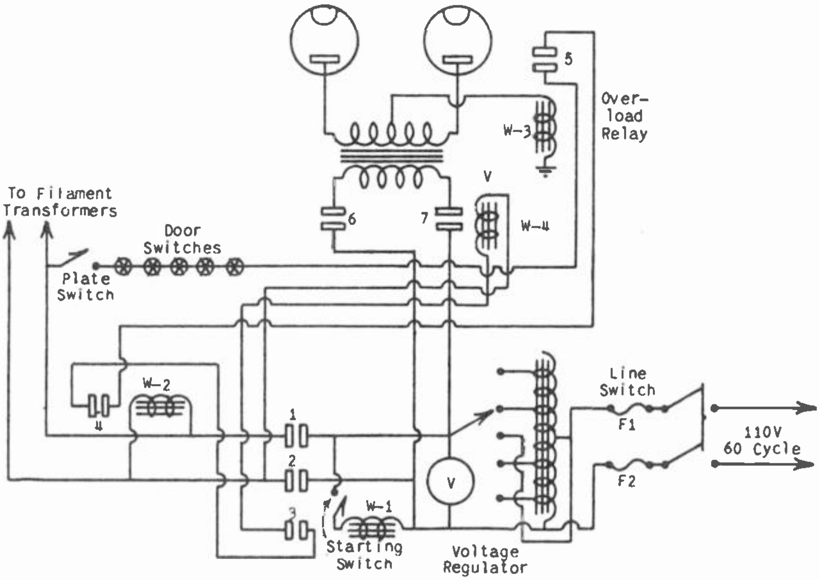


Fig. 17 Simplified diagram of the power controlled circuit in one of RCA's 100 watt transmitters.

It consists of two windings, W-3 and W-4; one end of W-3 is grounded and the other connects to the negative of the high voltage rectifier. Thus, all current drawn by the power amplifier tubes flows through winding W-3. Should this current become excessive, it will make contact 24 and break contact 20. The breaking of contact 20 de-energizes relay 10, which opens contacts 21 and 22, de-energizing relay 11, which in turn, allows the solenoid to drop and opens the circuit through the three-phase transformer on the high voltage power supply. The closing of contact 24 connects winding 4 of relay 12 across the bleeder of the bias rectifier and thus maintains the transmitter in an inoperative condition until this circuit is broken by a reset push-button which is connected in series with W-4. Pushing this button breaks the circuit of W-4, allows contact 20 to be made again, and re-establishes plate voltage in the power amplifier unit.

The next type of control circuit to be described is the one used by the RCA Manufacturing Company in one of their 100-watt transmitters. A diagram showing the various relays employed in this transmitter is given in Fig. 17. Power is supplied to this transmitter at 110 volts, 60-cycles, single phase. The line passes through the line switch and a pair of fuses, F_1 and F_2, into the voltage regulator. Connected across the secondary of this voltage regulator is an AC voltmeter and the variable arm should be changed until this meter reads exactly 110 volts. The starting and stopping of this transmitter is entirely automatic. The closure of the starting switch completes a path through relay W-1, which closes contacts 1, 2, and 3. The closing of contacts 1 and 2 completes the circuit to all of the filament transformers used in the transmitter. In addition, relay W-2 is now energized. This relay is the time delay relay and is of the oil dash pot type. After a definite time interval, this relay closes contact 4, and now, assuming that all the doors are closed and that the plate switch is also closed, a path is completed from one side of the line through the plate and door switches through contact 5 of the overload relay, which is normally closed, through contact 4 of the time delay relay and contact 3 of the filament relay, through relay W-4 and back to the opposite side of the line. Thus, relay W-4 is energized and it closes contacts 6 and 7 which then causes plate voltage to be applied to the rectifier tubes in the transmitter.

In case of an overload, the excessive current will flow through W-3, the overload relay, and will open contact 5, thereby, opening the circuit of the relay W-4 and causing it to be de-energized, and to open contacts 6 and 7, which removes the plate voltage from the rectifier.

The power control circuit of a 100-watt transmitter manufactured by the Collins Radio Company is illustrated in Fig. 18. Power is fed to this circuit by means of a 3-wire, 110-volt line. There are four push buttons on the front panel of the transmitter. One is marked "filament start"; one, "filament stop", and the other two are plate start and plate stop buttons respectively. These buttons are of the non-locking type and return to their normal positions when the pressure placed upon them is released. When the filament start button is pressed, a circuit is completed from that side of the line marked "filament power" through the winding of relay W-1, through the filament-start button, through the filament-stop button, which is normally closed, and back to the common wire of the three-wire line. The energizing of relay W-1 closes the three contacts, 1, 2, and 3. The closing of contact 3 provides a path for current to flow through the relay coil W-1, even after the filament-start button is released. It is to be noticed that contact 3 is connected directly in parallel with the filament-start button. At the same time, current may now flow from the side of the line marked "filament power" through contact 2 of relay W-1, through the primaries of transformers T_1, T_2, and T_3, thus supplying power to the low-voltage power supply which employs a high vacuum tube, and does not require a time delay. Furthermore, the energizing of transformers T_2 and T_3 supplies filament power to the entire transmitter.

At the same time the filament voltage is supplied to all the tubes in the transmitter, the green panel light is illuminated, indicating that relay W-1 has closed its contacts. Furthermore, the winding of the time delay relay is now energized, but its contacts do not close immediately. It is of the dash pot type and is filled

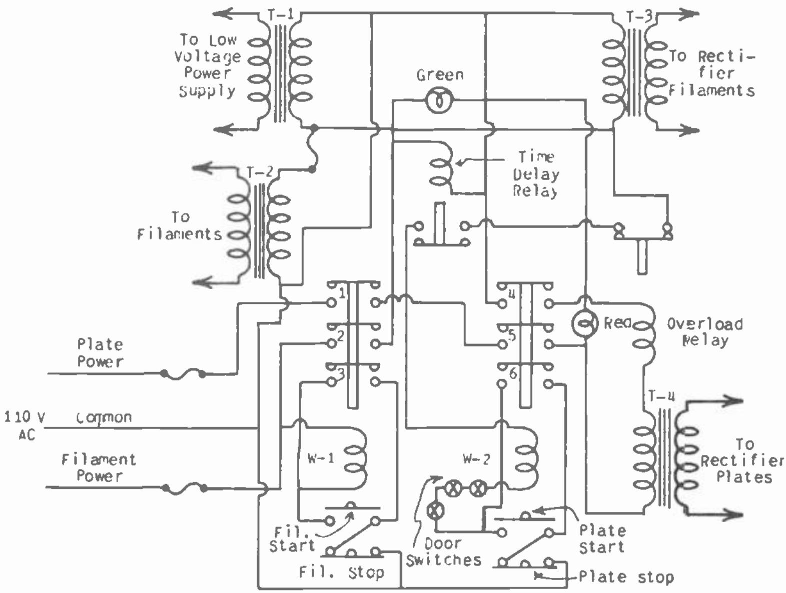


Fig.18 Power control circuit in one of Collins' 100-watt transmitters.

with a small quantity of oil. After a definite time interval, the plunger of the time delay relay is pulled up enough to close its contact and plate power may be supplied to the transmitter by the closing of the plate-start button. Closing the plate-start button causes current to flow from the line marked "filament power" through contact 2 of relay W-1, through the contacts of the overload relay which are normally closed, through the contacts of the time delay relay, through the winding of relay W-2, through the door switches (assuming that all doors in the transmitter are closed), through the plate-start button, and through the plate-stop button, which is normally closed, back to the common line of the three-wire power circuit. The energizing of relay W-2 causes it to close its contacts, 4, 5, and 6. Contact 6 is connected directly across the plate-start button, and as soon as the relay is closed, it will remain closed, even though the plate-start button is released. The closing of contacts 4 and 5 of relay W-2 complete the following circuit. Current may now flow from the line marked "plate power" through contact 1 of relay W-1, through contact 5 of relay W-2, through the primary winding of the rectifier plate transformer, through the overload relay, through contact 4 of relay W-2, and back to the common return line. At the same time a path is completed through the red panel lamp placed on the front of the transmitter, indicating that plate power is now being supplied to the tubes.

Depressing the plate-stop button will open the circuit through the winding W-2, thereby, de-energizing this relay. This will cause plate power to be removed from the transmitter. In a like manner, depressing the filament-stop button will de-energize relay W-1 and the opening of the contacts of this relay will remove not only the filament voltage from every tube in the transmitter, but the plate voltages of all tubes as well.

It is to be noted that in this particular circuit, the plate current of the tubes does not flow through the winding of the overload relay. Instead, the overload relay winding is connected in the primary circuit, which supplies power to the rectifier plates. In case a tube draws excessive current, this current will, of course, have to flow through the power supply and will re-act back up on the primary, causing an excessive primary current. This, in turn, will produce a large current flow through the winding of the overload relay, thereby, opening its contacts, which in turn will de-energize relay W-2 and remove all high voltages from the transmitter.

6. FREQUENCY MONITORS. The Federal Communications Commission requires that all broadcast stations maintain their frequency within 50 cycles plus or minus the frequency which has been assigned to them. To determine accurately that the frequency will be within this allowable range, it is necessary that some sort of frequency measuring device be available at the transmitter. At the present time, a frequency monitor is required in all broadcast stations. In general, this monitor consists of a very stable piezo-electric crystal oscillator, the output of which is beat against the carrier frequency of the transmitter. The beat note produced by the mixing of these two radio frequencies, is detected in a conventional detector circuit. Following the detector is some sort of frequency-deviation meter which indicates the difference in frequency between the carrier of the transmitter and the frequency of the monitor.

In the General Radio frequency monitor, the natural frequency of the crystal in the monitor itself is 1 kc. higher than the carrier frequency of the transmitter. If the transmitter is exactly on frequency, the mixing together of the carrier and the output of the monitor will produce a 1 kc. or a 1,000 cycle audio note in the plate circuit of the detector. The frequency-deviation meter which follows the detector is so arranged that it will read zero when the beat frequency is exactly 1,000 cycles. Should the transmitter frequency be either high or low, the beat frequency produced will be above or below 1,000 cycles and the frequency-deviation meter will deflect either to the left or right of its mid-position. This meter

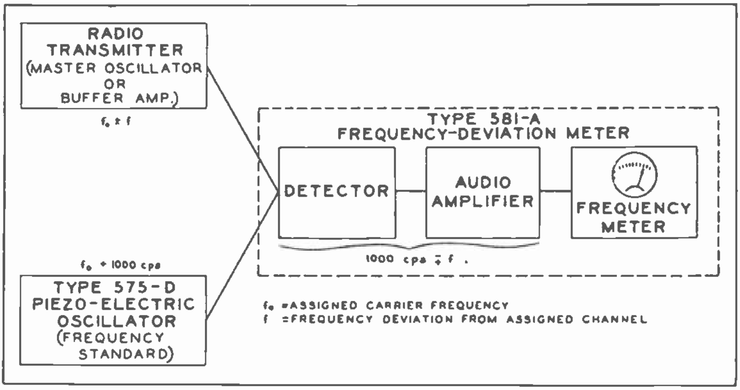


Fig.19 Block diagram illustrating the various parts of a frequency monitor.

is calibrated directly in cycles per second and from a reading of the meter, deviation of the transmitter frequency may be determined.

A block diagram of the General Radio frequency-deviation indicator is shown in Fig. 19. As may be seen, it consists of an oscillator whose crystal has a natural frequency of 1,000 cycles above the carrier frequency of the transmitter. The output of this oscillator is combined with a part of the transmitter's frequency and the two are mixed in the detector circuit. The output of the detector is fed to an audio amplifier, which in turn goes to the frequency-deviation meter. The frequency-deviation meter consists

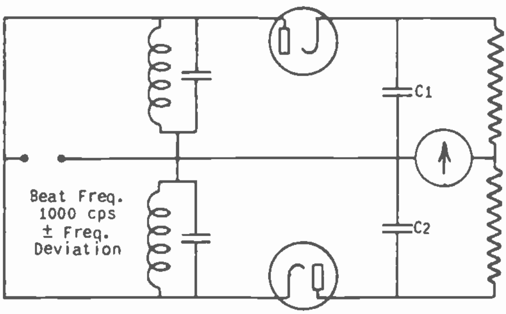


Fig.20 The circuit diagram of the frequency deviation meter in the General Radio frequency monitor.

of two tuned circuits, two tubes acting as diode rectifiers, a sensitive milliammeter having zero at its mid-scale, two by-pass condensers, and two compensating resistors. The diagram of the frequency-deviation meter appears in Fig. 20. The beat frequency is applied to the two tuned circuits in phase. One tuned circuit has a resonant frequency slightly above 1,000 cycles, whereas the resonant frequency of the other tuned circuit is an equal distance below 1,000 cycles. When the transmitter is on frequency, the beat frequency produced will be a 1,000-cycle signal. In this case, there will be the same voltage built up across each of the two tuned circuits since the 1,000 cycle signal will be just as far removed from the resonant frequency of one tuned circuit as it is from the other. Each tuned circuit is connected to a diode rectifier, so arranged that the rectified current from one diode will flow through the deviation meter in the direction opposite to that which the rectified current of the other diode flows. C_1 and C_2 are two by-pass condensers whose purpose is to by-pass the variations in the rectified current. As a result, only the average or DC component of the two rectified currents flow through the meter itself. When the 1,000 cycle signal is applied to the two tuned circuits, the same voltage will be built up across each of them, the same voltage will be applied to the two diodes and, in addition, the average value of the rectified current of one diode will be equal to that of the other. Since these two currents do flow through the meter in opposite directions, the net current flowing through the meter will be equal to their difference which, in this case, is zero.

Let us assume that the assigned frequency of the transmitter is 1,000 kc. or 1,000,000 cycles, but that for some reason or other, the actual carrier frequency is 10 cycles higher, or 1,000,010 cycles. The crystal oscillator in the frequency monitor will have a frequency 1,000 cycles above the assigned frequency of the transmitter, or will be 1,001,000 cycles. This will cause the beat frequency produced to be equal to the difference between 1,001,000 cycles and 1,000,010 cycles. In this case, it is 990 cycles. Since the resonant frequency of one tuned circuit is somewhat below 1,000 cycles, this 990-cycle signal will produce a greater voltage drop across this tuned circuit than it will across the one which is tuned at equal distance above 1,000 cycles. As a result, one diode will pass more current than the other, and the net current flowing through the deviation meter will be directly proportional to the amount that the carrier frequency of the transmitter differs from its assigned frequency.

In a like manner, if the carrier frequency of the transmitter is lower than it should be, the beat frequency produced will be greater than 1,000 cycles and again more voltage will be developed across one tuned circuit than across the other. This will also produce a net current through the deviation meter, but this time in the opposite direction, and so the meter will deflect oppositely from its mid-point position. A photograph of the General Radio frequency monitor appears in Fig. 21. The large meter in the upper center is the frequency-deviation meter. It is calibrated from 0 to 100 cycles, either side of its mid-point position. The other meters in the panel are for reading the currents and voltages of the oscillator, detector, and amplifier tubes. Notice that a thermometer is provided on the front panel for reading the temperature of the crystal oven.

It should, of course, be understood, that the accuracy of the frequency monitor is no better than the accuracy of the crystal oscillator employed in the monitor. It is not unreasonable to suppose that this oscillator will, from time to time, develop inaccuracies which make the reading of the frequency-deviation meter somewhat unreliable. If the frequency-deviation meter indicates that the carrier frequency of the transmitter is either high or low, there is always some doubt as to whether it is the oscillator in

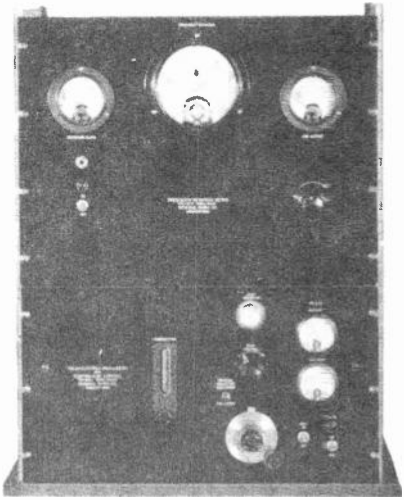


Fig.21 The General Radio frequency monitor.

the transmitter itself which is inactive, or whether the frequency monitor has drifted from its true frequency. For this reason, all broadcast stations subscribe to a frequency-monitoring service. Various companies which make this service available have standardized crystal oscillators and can, by tuning in the carrier of a broadcast station, beat it against their standard and thus determine the actual frequency of the broadcast station in question.

Naturally, the so-called standards against which the carrier frequencies are checked must themselves be checked against a standard of some sort. The standards used for this purpose are the frequency emissions transmitted by station WWV. This station has a definite schedule for transmitting various radio frequencies, both modulated and unmodulated for the sole purpose of checking oscillators throughout the country. The emissions of WWV are in turn standardized by being compared against an astronomical clock contained in the National Bureau of Standards at Washington.

In the final analysis, all frequency measuring systems must be checked against the rotation of the earth, which is the only primary standard of time available. Various astronomical clocks are maintained for the purpose of having a primary standard of time. Everything possible is done to make these clocks very accurate. They are placed in clock vaults where vibration will be at a minimum, and the temperature and humidity in the room containing the clocks are kept within very close limits. The accuracy of such an

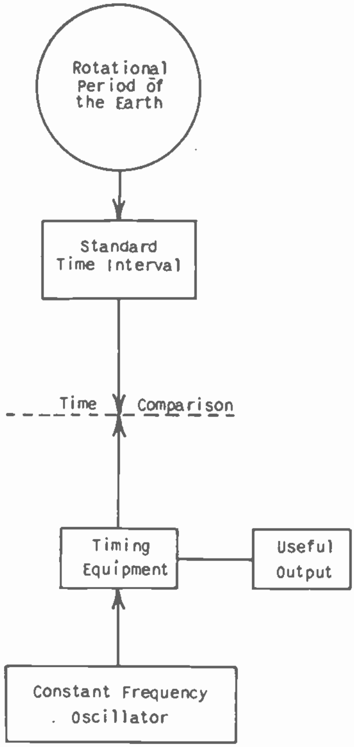


Fig.22 Illustrating the various parts of a primary frequency standard.

astronomical clock is checked periodically by sights upon various stars. The primary frequency standard itself is a very reliable piezo-electric crystal oscillator attached to a counting device which actually counts the number of cycles executed by the oscillator in a given time interval. This counter, in turn, operates a clock train and is so geared that when the frequency of the oscillator has a specified value, the clock indicates true time. By comparing the time of this clock driven by the oscillator against the standard astronomical clock, a very definite frequency check can be made. Then, by using various sub-harmonics of the oscillator frequency, other standards may be derived. Fig. 22 shows a block diagram of a primary frequency standard. It is to be noticed that the frequency of the primary standard is measured by direct comparison with the rotational period of the earth. Fig. 23 shows an interior of the time signal room at the U. S. Naval Observatory. At the left is a General Radio standard 1 kc. generator which drives a synchronous clock.

The next frequency monitor to be described is the Western Electric Type 1A, a diagram of which appears in Fig. 24. This unit incorporates a piezo-electric crystal oscillator, the crystal of which is in a constant-temperature oven. The temperature-regulator tube, similar to the one used in Western Electric transmitters, is employed to regulate the flow of heat to the oven.

The monitoring unit is able to indicate a frequency deviation of plus or minus 75 cycles of the carrier wave from its assigned frequency. The oscillator in the monitor unit has a frequency the same as the carrier of the transmitter. A small antenna is employed to pick up the radio frequency voltages from the transmitter, although it is possible to determine frequency variations by connecting the monitor to a receiver tuned to the transmitter frequency. Operation of the monitor is as follows:

The radio frequency voltages from the transmitter are picked-up by the small antenna and are then applied to the grid circuit of the tube V1. R1 is a gain control used to vary the input to the grid circuit of this tube. This tube has for its load, the primary of the radio frequency transformer T1. This radio frequency vol-

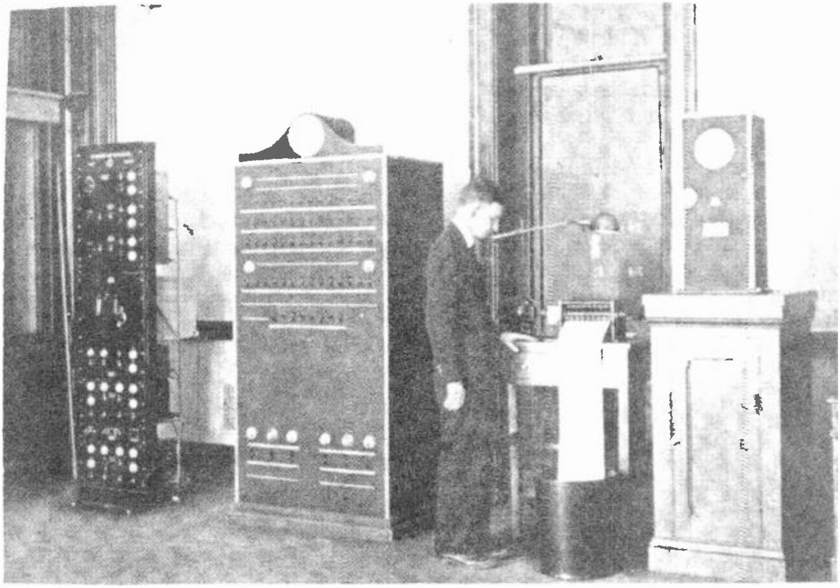


Fig.23 The time signal room at the U.S. Naval Observatory

tage is then applied to the grid circuit of the tube V2, which is biased to operate as a grid-bias detector. The plate current of the tube V2 will consist of unilateral pulses of radio frequency. These pulses will not be able to pass through condenser C3 and the highly inductive winding of the relay W-1 and are therefore by-passed through the R.F. by-pass condenser C1.

The output of the oscillator in the monitor unit is amplified by the tube V3, whose load is also the primary of the radio frequency transformer T_1. Thus, there is also impressed upon the grid circuit of the detector tube V2 another radio frequency voltage and if the transmitter is on its assigned frequency, this voltage will have the same frequency as that due to the carrier. In this case, both of the radio frequency components in the plate circuit of the detector tube will be by-passed through condenser C_1 and there will be no varying current through the relay W-1.

Let us assume that the frequency of the transmitter is 25 cycles higher than that of the oscillator in the monitor unit. There will then be produced in the plate circuit of the detector tube a beat frequency having a frequency of 25 cycles per second. This beat frequency being in the audio range will not be by-passed by the condenser C_1, but will flow through condenser C_3, through the winding of relay W-1 and through the resistor R3 to ground. With the resistor R3 in the circuit, there will not be enough current flowing through the winding W-1 to cause it to attract its armature. And so, when it is desired to take a frequency reading, the push button SW-1 is depressed, thereby shorting out resistance R3. When this is done, there will be sufficient current flowing through W-1 to cause it to close contacts 1 and 2 and thus charge condenser C4. It is to be noticed that contact 1 is connected to B+ and the closing of contacts 1 and 2 causes a charging current to flow into condenser C4.

Relay W-1 is a fast-acting relay and when the audio pulse has passed, the relay is de-energized, thus allowing contacts 1 and 2 to be broken and making contacts 2 and 3. The making of contacts 2 and 3 causes the condenser C4, which is now charged, to discharge through resistor R4 and the frequency-deviation indicator M-1. The condenser C5 and the resistor R4 provide the necessary damping effect on the moving element of the meter M-1.

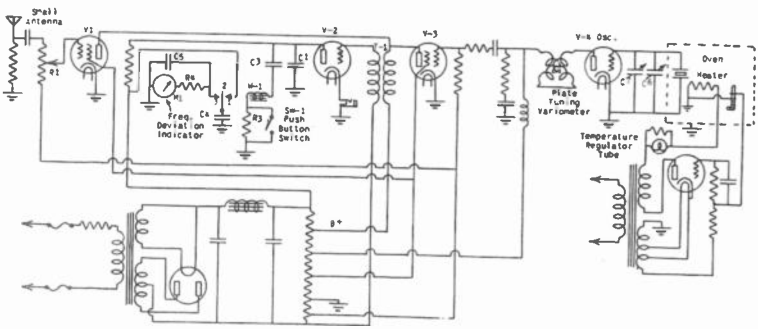


Fig.24 The circuit diagram of the Western Electric frequency monitor.

The greater the deviation of the carrier frequency of the transmitter, the higher will be the beat frequency produced in the plate circuit of the detector and the greater will be the rapidity with which condenser C4 is charged and discharged. This will cause the average current through the meter M-1 to be larger and it will deflect a greater amount.

It is to be noticed that the reading of the meter is dependent only upon the difference in frequency between the transmitter and that of the oscillator in the monitor unit. Thus, the meter will indicate a deviation of 25 cycles when the carrier frequency is either 25 cycles above or below its assigned value. To determine the direction of the deviation in frequency, the frequency of the monitor crystal is altered slightly. This is accomplished by inserting an extremely small capacity C6 across the crystal. The same push button which closes the test switch SW-1 also operates this condenser. Depressing this button gently causes the small condenser C6 to be varied toward minimum capacity by separating two small circular metal plates. As the push button is released, the capacity of C6 increases very slightly as the plates move closer together. Now let us assume that the indicator switch SW-1 is closed and the deviation meter reads 25 cycles. Now the push button is very slightly depressed and released, and again the deflection of the indicator is noted. If the meter tends to deflect slightly upward, it indicates that the transmitter frequency is 25 cycles above that of the monitor frequency. Let us see why this is so. Suppose that the assigned frequency of the transmitter is 1,000 kc. or 1,000,000 cycles and that the frequency of the monitor is exactly 1,000,000 cycles. Assume that the transmitter is 25 cycles above its assigned frequency or is 1,000,025 cycles. The deviation meter will indicate 25 cycles, but it has not been determined whether the transmitter frequency is above or below the monitor frequency. If, however, the meter deflects upward when the button is released, it is definitely known that the transmitter frequency is above the monitor frequency, because releasing the button increases the capacity across the crystal of the monitor oscillator and thus lowers its frequency. Lowering the frequency of the monitor below 1,000,000 cycles will increase the difference between the frequency of the monitor and that of the transmitter, which is high. Thus, the difference or beat frequency will be greater than 25 cycles, and the deviation meter will tend to move slightly upward. On the other hand, if the transmitter frequency is less than that of the monitor, releasing the button in this manner, will again lower the frequency of the monitor, reduce the frequency difference between the carrier and the monitor and cause the needle of the deviation meter to deflect downward. Hence, the small capacity connected across the crystal alters the monitor frequency very slightly and enables the operator to determine the direction of the frequency shift.

The condenser C7 which is also connected across the crystal oscillator is permanently adjusted to half capacity at the time of frequency calibration, so as to provide good flexibility. Condenser C7 is varied only when it becomes necessary to recalibrate the oscillator in the monitor unit.

7. MODULATION MONITORS. Modulation monitors are made in many different forms. Perhaps the simplest type is the diode rectifier circuit such as the one shown in Fig. 25. A small coil L1 introduces a portion of the modulated R.F. wave from the output of the transmitter. The tank circuit L2C1 is tuned to the frequency of the carrier; the R.F. voltages built up across this tank circuit cause the plate and grid of the tube to be driven alternately positive and negative. During the positive alternations, the diode passes current, the rectified current flowing from cathode to plate and grid, through the tuned circuit to ground, from ground up through the primary of the transformer T1, and through the meter M1 and the resistor R1.

The meter M1 will read the average value of the rectified diode current. C2 is the radio frequency by-pass condenser used to keep the radio frequency component of the rectified current from flowing through the primary of the audio transformer. If the carrier is not modulated, there will be no reading on meter M2, since no audio voltages will be developed across the winding of the transformer T1. The coupling between the diode rectifier tank circuit, and the transmitter is adjusted until meter M1 reads a predetermined value. When the carrier is modulated, the audio component of the rectified current will develop a voltage across the primary of the transformer T1 which will be transferred to the secondary. This audio voltage is fed to a copper oxide rectifier across whose terminals is connected a DC meter. This meter will then read the average of the audio voltages, and the reading of the meter will be directly proportional to the percentage of modulation of the carrier. R1 is a calibrating resistor which is varied only when it is necessary to recalibrate the monitor. The reading of the meter M1 should be the same with or without modulation. Any change in this meter during modulation indicates carrier shift. Carrier shift will be produced if the positive alternations of the modulation envelope are not equal to the negative alternations.

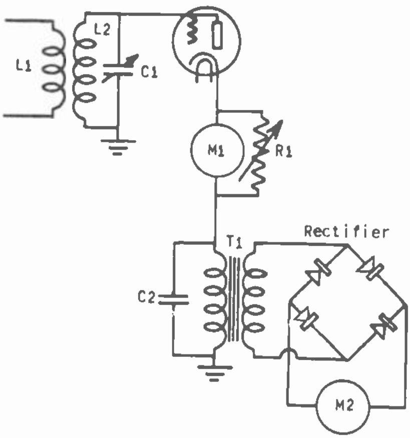


Fig.25 A simple type of modulation monitor.

This, of course, is a very simple type of modulation monitor. and is not representative of the types used in broadcast transmitters. It was included in this text merely to show that the percentage of modulation may be measured without elaborate equipment, if the need arises.

Modulation monitors used in broadcast stations should have the following requirements: (A) A DC meter for setting the average rectified carrier at a specific value and for indicating changes in carrier intensity during modulation. This meter is often called a "carrier shift meter". (B) A peak indicating light that may be set to flash at any predetermined value from 50 to 120% modulation on positive peaks and from 50 to 100% modulation on negative peaks. (C) A semi-peak indicator, with a meter having such characteristics that peaks of modulation of duration between 40 and 90 milli-seconds[1] will be indicated to 90% of full value. Further, the meter should be so designed that the pointer returns from full reading to 10% of zero within 500 to 800 milli-seconds. (D) A switch should be incorporated within this meter so that it may read either positive or negative modulation and, if desired, in the center position, it may read both in a full wave circuit.

[1] A milli-second is one-thousandth of a second.

The characteristics of the meter itself are as follows: The time for one complete oscillation of the pointer shall be between 290 and 350 milli-seconds. The useful scale length of the meter shall be at least 2.3 inches. The meter shall be calibrated for modulation from 0 to 110% and in decibels below 100%, with 100% being 0 db.

The accuracy of the readings of the meter shall be at least ±2% for 100% modulation and ±4% of full scale reading at any other percentage of modulation. The frequency characteristic curve must be practically flat from 30 to 10,000 cycles. It should not vary more than ±½ db. throughout this range.

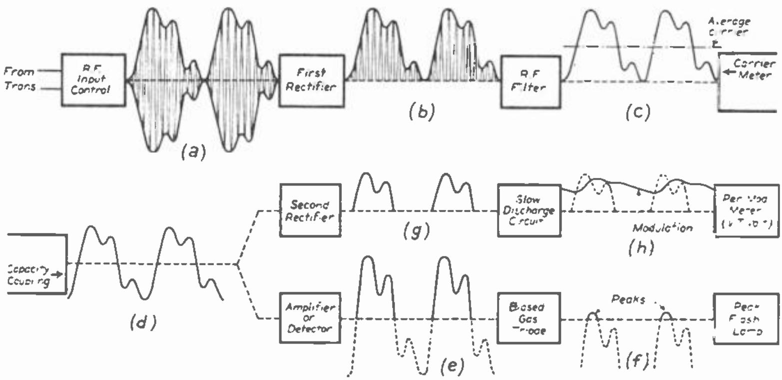


Fig.26 Block diagram illustrating the function of the various parts of a modern modulation monitor.

The modulation monitor is shown in diagrammatic form in Fig. 26. A portion of the modulated wave from the transmitter is fed to an R.F. input control. This is merely a gain control so that the strength of the signal into the modulation monitor may be changed as desired. The modulated carrier is then fed to a diode rectifier, which, of course, eliminates the negative alternations of the R.F. cycles. An R.F. filter is now provided and the output of this filter is the audio component of the modulated wave. This audio component flows through the carrier shift meter which reads the average value of the audio wave. By capacitive coupling, the audio component is now amplified and from this point it takes two paths. One is through a second rectifier which eliminates all but the positive alternations of the audio component. These positive alternations are then fed to a slow discharge circuit, consisting of a condenser and resistor, so designed that the voltage across the condenser will at all times be very nearly equal to the peaks in the audio signal. The voltage across this condenser then is applied to a vacuum tube voltmeter in whose output circuit is the semi-peak indicator.

The other path taken by the amplified audio is through either an amplifier or detector; it matters little which, since the purpose of the stage is to increase the amplitude of the positive alternations. These amplified positive alternations are applied to a biased gas triode, so adjusted that when peaks of the audio exceed a predetermined value, they will cause the gaseous tube to break down and, in so doing, the tube will operate a lamp which is the peak flasher lamp.

The problem of meter speed deserves somewhat further attention. There are, in general, three different types of meter; the fast acting, the slow speed, and the general purpose models. The slow speed meter has a characteristic of rising very slowly, requiring approximately ½ second to reach full scale deflection. Its obvious advantage is the fact that its movement is easily and comfortably followed by the eye. A decided disadvantage, however, is the fact that on peaks of ordinary duration it does not reach or even approach

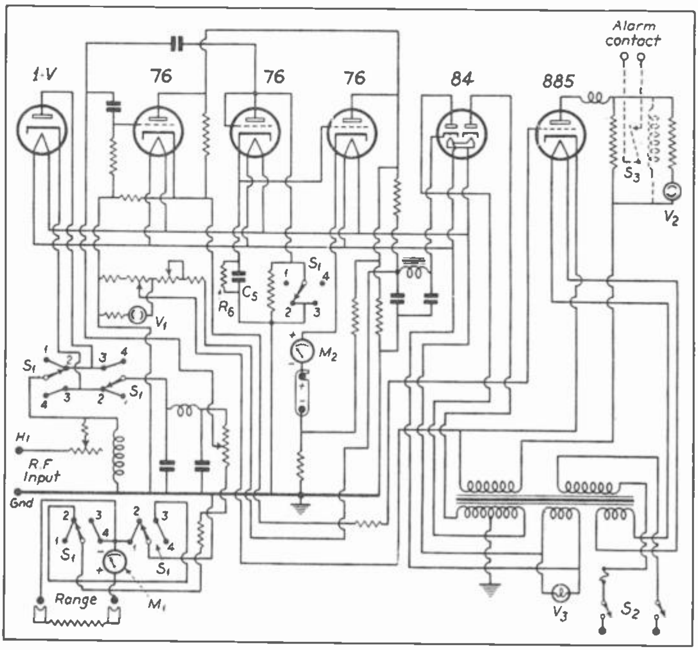


Fig.27 Circuit diagram of a modern modulation monitor.

the true peak reading. For example, on a peak lasting one-tenth second, it reads 10 db low. Contrasted to this, the high-speed meter rises very rapidly, reaching true level in one-tenth second, and for average peaks it reaches or comes very close to true level, but it has the very decided disadvantage of being difficult to follow and is uncomfortable as a means of continuous monitoring. The so-called general purpose meter is merely a compromise between the two. Its characteristics are most satisfactory for ordinary use. All three, however, leave something to be desired.

It is apparent that the ideal indicator would be one which reached its true reading in a very short time and held this reading for sufficient time to enable easy observation. As previously stated, a meter having an oscillation time of 200 to 350 milli-seconds is required. This refers to the meter only as distinguished from the meter together with the discharge circuit. This meter, however, requires 90 milli-seconds to reach 90% of true level, whereas the requirements stated that 90% indication for peaks with duration between 40 and 90 milli-seconds should be indicated. To obtain 90% indication for a peak lasting only 40 milli-seconds, the current passed by the second rectifier is used to charge a condenser which stores the energy long enough for the meter to come up to the desired reading. This same condenser discharges into a high resistance of approximately 50 megohms and hence the discharge rate is very slow. This action provides a slow rate of return; that is, to 10% of 0 within 500 to 800 milli-seconds, as previously stated was a requirement. When a peak of modulation occurs, the meter pointer

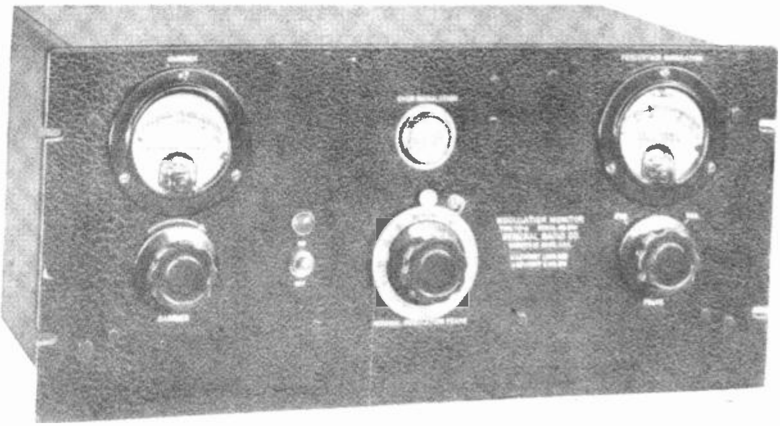


Fig. 28 The General Radio Modulation monitor.

begins to rise and if the peak is at least 40 milli-seconds in duration, the needle of the meter will reach a deflection of 90% true level. For peaks of longer duration, the needle will reach a deflection of from 90% to 105%. When the peak is past, the pointer returns very slowly, corresponding to the slow discharge rate of the condenser and for ordinary modulation, will not return to zero, but rather will provide between peaks a floating reading. By this means, the peaks of the envelope of the modulation are accurately indicated and at the same time, the wild gyrations of the pointer which would otherwise accompany the high speed action are eliminated.

The circuit diagram of the RCA #66A modulation monitor is shown in Fig. 27. The tubes reading from left to right are a 1V, which serves as a first rectifier, a type 76, which serves as a second rectifier for the peak flasher lamp, a type 76 which serves as an amplifier or detector for the semi-peak indicator, a type 76 which acts as a vacuum tube voltmeter to operate the semi-peak indicator, a type 84, which is the power supply rectifier for the instrument, and a type 885, which is a biased gas triode, which in turn operates the peak flasher lamp. The meter M1 in the lower left hand corner is a carrier-shift meter which reads the average value of the rectified current. The meter M2 is a semi-peak indicator. R6 and C5 constitute the slow discharge circuit for this modulation indicator. Reversing switches are provided so that either positive or negative modulation may be measured. A photograph of the General Radio type 731A modulation monitor appears in Fig. 28. It operates on practically the same principle as the RCA monitor which has just been described.

8. **DISTORTION MEASUREMENTS IN THE BROADCASTING STATION.** The General Radio Company has now made available a distortion and noise meter which measures the harmonic distortion in the transmitter with 400 cycle modulation, and the noise level in decibels below any given modulation level. A diagrammatic outline appears in Fig. 29. The carrier of the transmitter is modulated at 400 cycles and is then applied to the input of the instrument. The capacitive attenuator is provided to adjust the carrier level to a convenient value. This need not be changed after the first preliminary adjustment. The carrier is next rectified by a linear diode detector. From the output of the detector, the rectified current passes into a low-

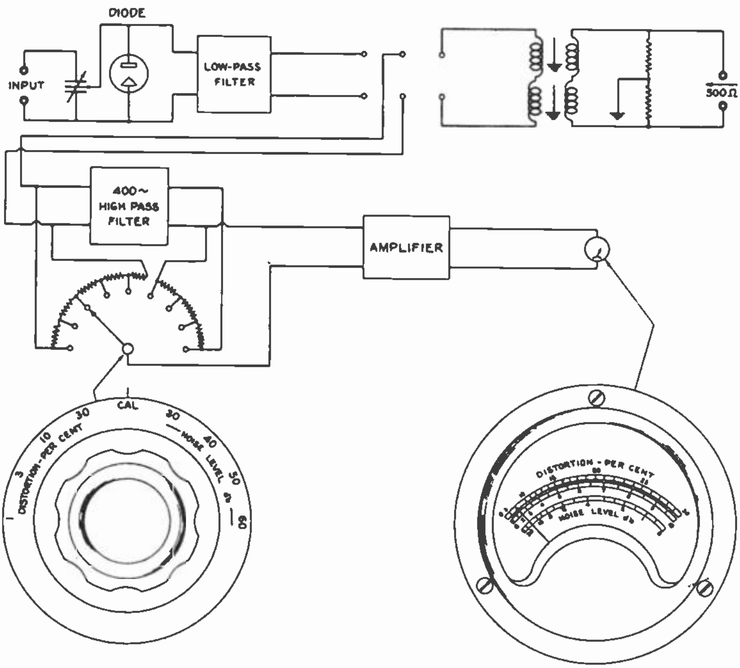


Fig. 29 Block diagram of the General Radio distortion and noise meter.

pass filter which rejects the radio frequency component and allows only the 400 cycles to pass through it. To standardize the direct reading scales, a known fraction of the audio frequency output is then applied to the amplifier and the gain adjusted to give full-scale deflection on the output meter. This is done at the CAL position of the attenuator.

To measure distortion, the 400-cycle component is then filtered from the signal and a known fraction of the remaining harmonics is applied to the amplifier whose output meter is now direct reading in the distortion range. The instrument has four scales, 1%, 3%, 10%, and 30% distortion, and all are direct reading, as is indicated in the drawing of the meter which is a reduced reproduction of the actual scale.

If the 400-cycle modulated wave is not distorted in any manner, there will be no modulation left on the carrier after it is passed through the filter which takes out the 400-cycle component. On the other hand, if during modulation, the 400-cycle note is distorted, harmonics will be generated which will still be present after the fundamental of 400 cycles has been removed.

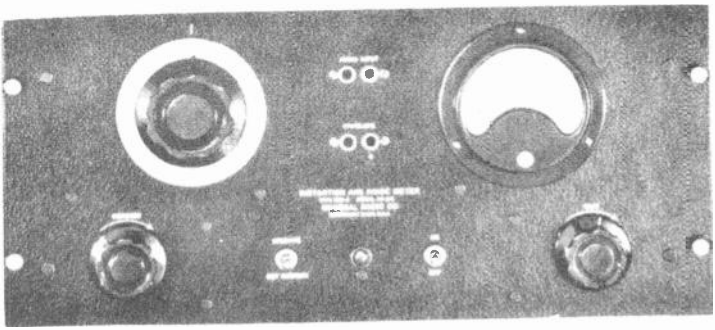


Fig.30 The front panel of the distortion and noise meter manufactured by the General Radio Company.

This same instrument may be used to measure the noise and hum contained in the carrier wave. For this measurement, the transmitter is modulated with a 400-cycle note; the dial is set to CAL for the purpose of adjusting the gain of the amplifier in the distortion and noise meter. When this gain has been adjusted to a convenient value, the unmodulated carrier is now applied to the input of the distortion and noise meter and the meter itself then measures the residual audio components of the carrier envelope. These audio components consist of noise voltages and hum voltages. The ratio of noise to signal is given directly in decibels on a third meter scale. It is to be understood that there are three scales on this meter, one is calibrated in per cent, and is for the purpose of measuring the per cent of distortion in a modulated R.F. wave, the second measures the actual db level of the noise in the unmodulated wave, and the third indicates the ratio of noise to signal. A photograph of this combined distortion and noise meter appears in Fig. 30.

Notes

(These extra pages are provided for your use in taking special notes)

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POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 4

DECIBELS AND MICROPHONES

LESSON NO. 2

"MIKE"

.....interesting, important, tricky.

Innocent 'Mike', as the microphone is frequently termed, is not nearly so innocent as he appears.

Supported by a stand or hanging from the studio ceiling, 'Mike' looks like a little metal contraption of no consequence. But he really is very important, as you will discover when you have completed this lesson.

Frequently famous people have entered a studio to make an address to their invisible audience, with all the confidence in the world. But when the time comes for them to 'go on the air' and they are face-to-face with 'Mike' they grow pale with fear, even though they know that poor little 'Mike' cannot bite them.

And 'Mike' plays tricks too. We well remember a certain instance when the microphone in a studio was left open and some embarrassing remarks went out on the air to the ears of thousands of listeners. If 'Mike' were human we know that he would hold his sides with glee and laugh his little head off.

Many times during the past years, the safety of a huge airliner has depended upon the proper functioning of 'Mike'. He has played an important role in the capture of criminals. You will find him in gorgeous studios, in the cockpit of swiftly moving airplanes, in ground radio stations, police cars and in many other places.

Yes, little 'Mike' is a mighty interesting and important fellow. And you must know all about him. So study this lesson on 'Mike' thoroughly and remember that he will play an important part in your future success.

Hats off to little 'Mike'.

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Lesson Two

DECIBELS and MICROPHONES

"The study of the decibel can be made quite complicated, but this need not be the case. If you will look at the easy and interesting side of this unit you will find that it has many applications, all readily applied by following the directions given in this lesson.

"Volumes could be written about microphones, but in this lesson we are going to give you only the necessary essentials about a few of the most popular types."

1. SOUND. It is the purpose of this lesson to inquire into some of the mysteries of the decibel, and to impart a general idea of the construction and operation of some of the more commonly used microphones. Before an understanding of the decibel is possible, it is necessary that the need for such a unit be explained. It has been determined that the responses of the five human senses are not in direct proportion to the strength of the stimuli producing them. The eye, for example, is able to respond to light intensities having a ratio greater than a million to one, such a ratio corresponding approximately to the difference between moonlight and bright sunlight. In a like manner, the human ear can accommodate itself to weak sounds having only one-millionth as much pressure as the loudest sound which may be listened to without actual physical discomfort. Thus, it would appear that the eye and ear are truly remarkable in their ability to respond to such a wide variation in the intensity of the stimulus.

So far as the width of their sensitivity ranges are concerned, the eye and ear surpass any common measuring instrument with which we are familiar. It is common knowledge that no measuring instrument is able to detect an effect which is smaller than one-thousandth of that required to produce full-scale deflection. For no matter what the range of the instrument might be, it would not be possible to read anything smaller than one-thousandth of the full scale. The eye and the ear, on the other hand, may easily be influenced by an effect which is only one-millionth of the maximum; and so it appears that these wonderful organs have a response one thousand times as great as any ordinary measuring instrument.

The fact that both the eye and the ear do have such a wide range of sensitivity is due to the fact that both are very flexible measuring instruments. As the stimulus exciting them is increased, their sensitivity is automatically cut down by some physiological adjustment. Were it not for this characteristic, it would not be possible for them to respond to such a wide range of stimulus without discomfort. Thus, it is seen that these two organs are equipped with a device which is very similar to an automatic volume control circuit of a radio receiver. Just as the AVC circuit reduces the sensitivity of the radio set for strong signals and increases the sensitivity when the set is receiving a weak signal, so do the eye and ear change their sensitivity with changes in the strength of the stimulus.

The fact that the sensitivity of the organs of seeing and hearing does change is easily verifiable. We have all experienced the familiar "sun-blindness", occasioned by entering a darkened room after being in bright sunlight. While we were in the sunlight, our eyes were relatively insensitive, so that they could accommodate the comparatively strong stimulus produced by the sun's rays. In the darkened room, the stimulus was rather weak, and distinct vision was impossible until enough time had elapsed for our eyes to become accustomed to the darkness of the room. The same phenomenon is easily recognizable in the sense of hearing. It is common knowledge that a whisper is heard easily when the surroundings are quiet and our ears are very sensitive, but that in the midst of a heavy din, a whisper is lost, merely because the large amount of noise has made our ears relatively insensitive.

It has been determined that the smallest change in sound amplitude that the ear is able to perceive is roughly a constant percentage of the original intensity. The minimum percentage change that a well trained ear is able to detect is roughly 25%. This means that when the ear is hearing a given sound, the intensity of this sound must be increased 25% or must become 1¼ times as large for the ear to detect any difference. There are several different units which may be used to measure the intensity of a given sound. We may measure the pressure of the sound wave and thus express its intensity in pressure units such as dynes per square centimeter,[1] or we may measure the power in the sound and state it in microwatts per square centimeter. Since the power unit is the more common, it is the one which will be employed in this text. Using this unit, we find that the intensity of ordinary conversation is about 30 micro-microwatts per square centimeter ($30 \mu\mu w/cm^2$). During the peaks of the loudest sound encountered in conversation, the intensity increases to 15,000 $\mu\mu w/cm^2$, whereas the faintest whisper has an intensity of about .03 $\mu\mu w/cm^2$. Thus, the intensity range of ordinary speech is 500,000 to 1.

The ear is not a linear device; a sound of 10 $\mu\mu w/cm^2$ intensity does not sound twice as loud to the ear as one of 5 $\mu\mu w/cm^2$; the difference, however, is noticeable. Although an increase in

[1] Refer to Lesson 7, Unit 2, Page 7.

intensity from 5 $\mu\mu w/cm^2$ to 10 $\mu\mu w/cm^2$, is noticeable; an increase from 100 $\mu\mu w/cm^2$ to 105 $\mu\mu w/cm^2$ could not be detected by the ear.

2. LOGARITHMS AND THE DECIBEL. Before it is possible for us to understand fully the relationship between the strength of the stimulus and the response of the ear, it is necessary that we understand the meaning of a logarithm. Briefly, a logarithm is nothing more than an exponent. Let us, for example, consider the following table:

$$10^1 = 10$$
$$10^2 = 100$$
$$10^3 = 1000$$
$$10^4 = 10{,}000$$

In each case the exponent is the small number written slightly above and to the right of the 10, and the 10 itself is called the base. Thus, when the base 10 is raised to the second power, the number which results is 100. Another way of stating the same thing is to say that the logarithm of 100, to the base 10, is 2. Since all of the logarithms with which we shall deal will have 10 as the base, this part will be omitted, and the foregoing will be written as:

$$\log.\ 100 = 2$$

Where log is the abbreviation for logarithm.

Thus, the logarithm of a number tells us to what power 10 must be raised to equal the given number. For example, if the given number is 1000, we know that 10 must be raised to the third power to equal the given number, so we say that the log 1000 is 3.

And so, it is easy to see that the log of 100 is 2 and that of 1000 is 3, but to determine the logarithm of some number between 100 and 1000 is a slightly more difficult matter. Suppose that the logarithm of the number 200 is desired. It is clear that the logarithm is somewhere between 2 and 3, but just what its value may be, is not determinable by inspection. The logarithm of any number which is not an exact power of 10 must be found from a table of logarithms. Since it is not necessary for us to inquire into the nature and use of logarithms to this extent, we will merely state that the logarithm of 200 is 2.301. This means that $10^{2.301} = 200$. In a like manner, it may be determined that the logarithm of 5 is .6990, of 50 is 1.6990 and of 500 is 2.6990.

Since the response characteristic of the ear is logarithmic: that is, since an increase in intensity of from 1 to 10 units produces the same apparent increase in loudness as an intensity increase of from 10 to 100 units, it would be very convenient to use some sort of unit founded on this principle. Furthermore, there are other uses to which this unit could be employed to advantage. It is well known that the power taken from the receiving end of a telephone line is less than is put into the sending end of the same line; that is, the telephone line attenuates[1] the signal. The amount of attenuation is not, however, so many watts per mile, but depends on the amount of power present in a given section of the line. Thus, each section of the line attenuates the power by a definite percentage. For example, each mile of the line might reduce the amount of power in the signal by one-half. If the power put into the line was 2 watts, the first mile would cause an attenuation of 1 watt, the second mile of $\frac{1}{2}$ watt, and the third mile of $\frac{1}{4}$ watt, etc. Thus, the relation between the length of the line and the attenuation is logarithmic, or exponential. Ten miles of this line would cause an attenuation of $(\frac{1}{2})^{10}$, or the power at the receiving end would be only $\frac{1}{1024}$ of that put into the sending end.

Although the decibel is the present unit which is founded on the logarithmic principle, its predecessor was the so-called telephone unit (T.U.), which was the attenuation provided by a mile of standard telephone cable. This cable was of 19 gauge wire, and had a resistance of 88 ohms per mile and a capacitance of .054 mfd. per mile. Of course, the actual amount of attenuation of this mile of standard cable depended on the frequency under consideration, it being natural that a higher frequency would be attenuated more than a low one, because the capacitive reactance of the distributed capacity would be less the greater the frequency. For this reason, a standard frequency of 800 cycles was usually employed in attenuation measurements.

Dissatisfaction of the telephone unit grew, because it was at best an artificial unit, designed for a particular type of cable. Therefore, it was finally replaced by the unit decibel. The fundamental unit is the bel, named in honor of Alexander Graham Bell, the father of the telephone. By definition, the bel is the logarithm, to the base 10, of the ratio of the output power to the input power. For example, if the power put into a telephone line is 10 watts, and the power at the receiving end is only 1 watt, then the ratio of the output power to the input power is 10. The logarithm of 10 is 1, and it is said that the attenuation of this particular line is 1 bel. Notice that the unit bel does not take into account either the amount of input power or output power, but only the ratio between the two powers; thus, whenever a telephone line causes a reduction in the power of one-tenth, it has an attenuation of 1 bel. Furthermore, it was determined that the attenuation of the mile of standard cable at 886 cycles was exactly equal to .1 bel. Thus, the commonly used attenuation unit has come to be the decibel, which is one-tenth of a bel. By definition, the decibel is ten times the logarithm of the power ratio. It is usually abbreviated to db and expressed as an equation, it is:

$$Db = 10 \log \frac{P_2}{P_1}$$

Where: P_2 and P_1 are the output and input powers respectively.

[1] To attenuate, as you will remember, means to weaken.
[2] Refer to Lesson 21, Unit 1.

Let us, for example, suppose that the output power of a telephone line is only one - one - thousandth of the input power. This means that the ratio between the power input and the power output is 1000. The logarithm of 1000 is 3, and ten times this value produces 30 db. Thus, the attenuation of this line is 30 db. Now suppose that the output of the telephone line is connected to an amplifier having a gain of 100. The total attenuation of the line with the amplifier connected is $\frac{1}{1000} \times 100$ or $\frac{1}{10}$. This means that the ratio of the input power to the output power is 10. The logarithm of 10 is 1, and ten times this is 10. Therefore, the total attenuation of the line and amplifier is 10 db. The problem could be solved more easily by finding the number of db corresponding to a gain of 100, (the gain produced by the amplifier). This is permissible, because the decibel is used to express gains as well as attenuations. In this case, the gain of the amplifier expressed in decibels would be:

$$\begin{aligned} db &= 10 \log 100 \\ &= 10 \times 2 \\ &= 20 \text{ db} \end{aligned}$$

Now knowing that the attenuation of the line itself is 30 db, and that the amplifier itself produces a gain of 20 db, is it not logical to assume that the total attenuation of the line with the amplifier connected is equal to the difference between the amount of attenuation and the amount of gain? Assuming that this is so, it is clear that the total attenuation is:

$$30 \text{ db} - 20 \text{ db} = 10 \text{ db.}$$

Remember that fundamentally the decibel unit is nothing more than a ratio. It is not a concrete unit; we cannot say that a certain amount of power is equal to so many decibels, as this has no meaning. It is merely a unit used to express the ratio of two power levels. Thus, nearly all amplifiers are rated in dbs. The db rating being determined by multiplying the logarithm of the power ratio by 10.

Since it is unlikely that the gain of an amplifier or the attenuation of a telephone line will be an exact power of 10, it would be necessary to refer to a table of logarithms to determine the db. equivalent. However, in order to make this procedure as simple as possible, a table has been included in this lesson from which the information may be obtained directly. This table is shown in Fig. 1.

Note that this table has seven columns. For the present, we are concerned only with the middle three columns. These are the ones headed power ratio gain, decibels, and power ratio loss. Suppose, for example, that we wish to learn what power ratio corresponds to a gain of 12 dbs. In the fourth column, we find the number 12, and on the same line in the third column, we see that the power gain is 15.849. Thus, any device which would increase

GAIN				LOSS		
Power Level	Voltage Or Current Ratio	Power Ratio	DB	Power Ratio	Voltage Or Current Ratio	Power Level
.006	1.00	1.00	.0	1.	1.	.006.
.00614	1.012	1.023	.1	.9772	.9886	.00586
.00628	1.023	1.047	.2	.9550	.9772	.00573
.00643	1.035	1.072	.3	.9331	.9661	.00560
.00650	1.047	1.097	.4	.9120	.9550	.00547
.00673	1.059	1.122	.5	.8913	.9441	.00535
.00689	1.072	1.148	.6	.8710	.9331	.00523
.00705	1.084	1.175	.7	.8511	.9226	.00511
.00721	1.097	1.202	.8	.8318	.9120	.00499
.00738	1.109	1.230	.9	.8128	.9016	.00488
.0076	1.122	1.259	1.0	.7943	.8913	.00477
.0095	1.259	1.585	2.0	.6310	.7943	.00379
.0119	1.413	1.995	3.0	.5012	.7080	.00301
.0153	1.585	2.512	4.0	.3981	.6310	.00237
.0190	1.778	3.162	5.0	.3162	.5623	.00190
.0237	1.995	3.981	6.0	.2512	.5012	.00151
.0305	2.239	5.012	7.0	.1995	.4467	.00119
.0380	2.512	6.310	8.0	.1585	.3981	.00095
.0474	2.818	7.943	9.0	.1259	.3548	.00076
.060	3.162	10.000	10.0	.1000	.3162	.0006
.0755	3.548	12.589	11.0	.0794	.2818	.00047
.0951	3.981	15.849	12.0	.0631	.2512	.00040
.1197	4.467	19.953	13.0	.0501	.2239	.00030
.1507	5.012	25.119	14.0	.0398	.1995	.00023
.1897	5.623	31.623	15.0	.0316	.1778	.00019
.2389	6.310	39.811	16.0	.0251	.1585	.00015
.3007	7.080	50,119	17.0	.0200	.1413	.00011
.3786	7.943	63.096	18.0	.0158	.1259	.000095
.4766	8.913	79.433	19.0	.0126	.1122	.000076
.600	10.0	100.0	20.0	.0100	.1000	.000060
6.0	31.62	1,000.0	30.0	.0010	.0316	.000006
60.0	100.0	10,000.0	40.0	.0001	.0100	.0000006
600.0	316.2	100,000.0	50.0	.00001	.0032	.00000006
6,000.0	1,000.0	1,000,000.0	60.0	.000001	.0010	.000000006
60,000.0	3,162.0	10,000,000.0	70.0	.0000001	.0003	.0000000006
600,000.0	10,000.0	100,000,000.0	80.0	.00000001	.0001	.00000000006
6,000,000.0	31,620.0	1,000,000,000.0	90.0	.000000001	.00003	.000000000006
60,000,000.0	100,000.0	10,000,000,000.0	100.0	.0000000001	.00001	.0000000000006

Fig.1 Decibel conversion table.

the amount of power 15.849 times would be said to have a db gain of 12. If the power put into a certain circuit is 10 watts, and the circuit introduces a loss of 5 db, we can determine from the table what power output is available from the circuit. By finding the number 5 in the decibel column, and then noticing the corresponding number in column 5, we see that the power ratio is .3162, This means that the power output of the device is .3162 times the power input. Therefore, the power output is: .3162 × 10 or 3.162 watts. Column 3 is used to determine the power ratio considering that a gain is involved, and column 5 is used where there is a power loss.

It should be realized that successive loss or gain ratios must be multiplied to find the overall loss or gain. For example, suppose that one stage of an amplifier gives a gain ratio of 5 and another a gain ratio of 2. If the output of the first stage is used to feed the input of the second stage the overall gain ratio of the two stages will be 5 × 2 or 10. Thus, if the input to the first stage is 1 watt, the output of this stage will be 5 watts, and this amount of power applied to the second stage which has a gain of 2 would produce an output power of 10 watts. If the gains of these two stages are expressed in decibels, the total db gain of the two is determined by adding the db gain of each. For example: A gain ratio of 5 corresponds approximately to a db gain of 7 as may be found in the table. Also, a power gain of 2 is nearly equal to a db gain of 3. Therefore, the total db gain of the amplifier would be 7 db plus 3 db, or 10 db, and this is equal to an overall power gain of 10 times.

The foregoing principle may be used to determine power ratios corresponding to db gains which are not given directly in the table. Suppose, for example, that an amplifier has a gain of 44 db. This is equivalent to two successive gains of 40 db and 4 db. A 40 db gain corresponds to a power ratio of 10,000 and a 4 db gain is equivalent to a power ratio of 2.512. Thus, the overall power gain of the amplifier would be the same as that of two stages, one having a power amplification of 10,000 times, and the second an amplification of 2.512 times. It is evident that the total power gain is equal to 10,000 × 2.512 or is 25,120 times, and the power output of this amplifier is 25,120 times as great as the power input.

Again, suppose that a telephone line causes a loss of 10.4 db. What is the loss ratio? It is seen that the loss ratio corresponding to 10 db. is .1, and that of .4 db is .9120; therefore, the total loss ratio would be the product of .1 and .9120, or .0912. This means that the output power of the telephone line is .0912 times the input power.

We have now seen how it is possible to convert from decibels to the corresponding power ratio gains or losses. The opposite conversion is also possible. Assume that an amplifier produces an amplification of 50 times. In column three we find the number nearest 50; this is 50.119 which corresponds to a db gain of 17. Thus, the amplifier has a 17 db gain. It is possible, by use of this table to find the db gain of any device to the nearest tenth of a decibel. The following example will show how this is done. It is assumed that the input and output powers of an amplifier are measured, and that the ratio of the output power to the input power is found to be 23,470. It is at once evident that the db gain corresponding to this power ratio is not directly determinable from the table. By noting the figures in column three, however, it is seen that a power ratio of 23,470 is between the ratio of 10,000 (corresponding to a db gain of 40), and the ratio of 100,000 (corresponding to a db gain of 50 db). Thus, the db gain of this amplifier is between 40 and 50 db. The next step is to divide the power ratio of 23,470 by the ratio of 10,000 (the one next above it in the table). This gives 2.347. Now looking for a power ratio of 2.347 in column three, we find that it is between 1.995 (corresponding to a db gain of 3) and 2.512 (corresponding to a db gain of 4). Thus, it is clear that the ratio 2.347 is between 3 and 4 db and that the original power ratio is between 43 and 44 db. The next step is to divide the power ratio of 2.347 by 1.995 (the one next above it in the table. This gives: 2.347 ÷ 1.995 = 1.176. Now the power ratio nearest to 1.176 is found in column three. This is seen to be 1.175 which corresponds to a db gain of .7.

Therefore, the db gain corresponding to a power ratio of 23,470 is 40 plus 3 plus .7 or 43.7. By a similar method, the db gain corresponding to any power ratio may be found to the nearest tenth of a decibel.

This table is also useful for determining the db loss corresponding to any power ratio which represents a loss in power. For example, assume that the power output of a circuit is only .045 times the power input. This represents a power loss in which the loss ratio is .045. By referring to column five of the table, it is seen that this loss ratio is between .0501 and .0398, or is between 13 and 14 decibels. Thus, the first step is to divide the given ratio .045 by .0501 (the one next above it in the table). This produces:

$$.045 \div .0501 = .8982$$

By running through column five, it is seen that this ratio .8982 is between .8913 and .9120 corresponding to .5 and .4 db respectively. Since it is nearer to .8913, we shall assume that this loss ratio corresponds approximately to .5 db, and that the original loss ratio of .045 is 13.5 decibels to the nearest tenth.

3. VOLTAGE AND CURRENT RATIOS. Although the fundamental idea of the decibel is to express a power ratio in a logarithmic manner, it is sometimes used for current or voltage ratios as well. Let us determine how this is possible. From the original definition of the decibel, we learned that it was ten times the logarithm of a power ratio. The equation is:

$$Db = 10 \log \frac{P_2}{P_1}$$

P_2 and P_1 represent the output and input powers respectively. If the input impedance of a device is equal to the output impedance, then the foregoing formula may be changed as follows:

$$Db = 10 \log \frac{I_2^2 R}{I_1^2 R}$$

Where: I_1 is the input current,
I_2 is the output current,
R is the input and output impedances which are equal.

It is seen that the R's in the last formula may be cancelled, leaving:

$$Db = 10 \log \frac{I_2^2}{I_1^2}$$

$$= 10 \log \left(\frac{I_2}{I_1}\right)^2$$

Now, by a fundamental logarithmic principle, it may be proved that this formula may be converted to read:

$$Db = 20 \log \frac{I_2}{I_1}$$

And so, we have evolved a formula from which the db gain or loss may be calculated when the current ratios are known, provided that the input and output impedances are equal. Since the two impedances often are equal, this relationship will occasionally prove helpful. For example, suppose that a telephone line has an impedance of 500 ohms; naturally, the input and output impedances of this line will be equal. If the input current is 3.4 ma. and the output current is .816 ma., then the current loss ratio is:

$$\frac{.816}{3.4} = .24$$

Current loss ratios are given in column six of the table, and by running down this column, we find that a loss of .24 is between .2512 and .2239, corresponding to db losses of 12 and 13 respectively. The next step is to divide the given loss ratio .24 by .2512, the one next above it in the table. This gives:

$$\frac{.24}{.2512} = .9554$$

Now by looking through column six, we find that a loss ratio of .9554 is nearest to .9550 which corresponds to a db loss of .2. Thus, when the current loss ratio is .24, the db loss is 12 plus .2 or 12.2 db.

In a like manner, current gain ratios may be calculated. Also, since the power ratios are proportional to the square of the voltage ratios when the input and output impedances are equal, it is possible to derive a formula giving db losses or gains in terms of voltage ratios. This formula is:

$$Db = 20 \log \frac{E_2}{E_1}$$

Where: E_1 is the input voltage, and
E_2 is the output voltage.

Column two of the table is used for current or voltage gain ratios, and column six is used for voltage or current loss ratios. For example, suppose that a 500-ohm telephone line is connected to an amplifier, the output impedance of which is also 500 ohms. It is assumed that the amplifier is at the receiving end of the line and that its purpose is to compensate for the line losses. In fact, we shall assume that it does more than compensate for the line losses and that the output voltage of the amplifier is somewhat greater than the input voltage of the line. If the input voltage is 1.5 volts, and the output voltage from the amplifier is 3.15 volts, then we may determine the db gain of the line and amplifier as follows: The ratio of the output voltage to the input voltage is:

$$\frac{3.15}{1.5} = 2.1$$

We find in column two that this gain ratio is between 1.995 and 2.239 or between 6 and 7 db. By dividing the gain ratio of 2.1 by 1.995, we obtain:

$$\frac{2.1}{1.995} = 1.0526$$

This gain ratio is between 1.047 and 1.059 in column two, which correspond to .4 and .5 db respectively. Thus, the gain ratio of this line and amplifier is approximately 6.5 db.

4. USING DECIBELS TO EXPRESS POWER LEVELS. We have now made use of all the columns in the decibel table except the first and last. These two are labeled "power level". As has been repeatedly stated, the primary and fundamental purpose of the decibel is to express a power ratio, and any other purpose to which it may be put is at best artificial. However, just as it is sometimes convenient to express current or voltage relationships in terms of decibels, so power levels are often expressed in a like manner. And so, it is common practice to state that the power output of a certain amplifier is so many decibels. This is permissible as long as it is thoroughly understood that such an expression means merely that the power output of the amplifier is a given number of decibels above or below some power level which is arbitrarily taken as a standard or reference point. Suppose, for example, it is stated that the power output of an amplifier is 20 db. A 20 db gain, as may be noted in the table corresponds to a power ratio of 100; thus, the actual power output of this amplifier is 100 times some other power level, which has been adopted as a reference.

Naturally, it will not be possible to determine the power output of an amplifier in watts, when the output is given in decibels unless the reference level used is known. Unfortunately, there are three different reference levels in fairly common use today, and it is necessary to state which is being used. Perhaps the most common of the three is the one adopted by the Bell Telephone Laboratories. It is .006 watt, or 6 milliwatts. It is used by the telephone companies and by Western Electric in rating their various equipment. The next reference level in order of popularity is the one adopted by the RCA Manufacturing Company; it is .0125 watt or 12.5 milliwatts. The third reference level is .001 watt or 1 milliwatt and is the level which has been adopted by the United States Navy. Throughout this lesson, a reference level of 6 milliwatts will be employed.

When it is stated that the reference level is 6 milliwatts, it means that this amount of power shall be designated as 0 db.

Then, any amount of power in excess of 6 milliwatts will be denoted as a positive db level, and any power less than this reference will be designated as a negative db level. It may be seen from the table that a gain of 20 db is equivalent to a power ratio of 100; therefore, a power level of +20 db would be 100 times as great as the reference level of .006 watt, or would be .6 watt. Note that this value is given in column one opposite 20 db.

If the power level is less than the reference, the db level will be negative. For example, consider a power level of -20 db. A loss of 20 db represents a power ratio of .01; therefore, a level of -20 db would be .01 times .006 watt, or .00006 watt. This value is given in column seven opposite 20 db. Thus, it is seen that the first column is for positive db levels, and the seventh column for negative db levels. Suppose it is desired to know the db level corresponding to 1 watt. Since this is greater than .006 watt, the db level will be positive. By referring to column one, it is seen that 1 watt is between .6 watt and 6 watt. This is between 20 and 30 dbs. The next step is to divide the 1 watt by .006 watt to determine the power ratio. This is:

$$\frac{1}{.006} = 166$$

Since 20 db corresponds to a power ratio of 100, the next step is to divide 166 by 100, obtaining 1.66. Now by referring to column three, it is seen that 1.66 is between 1.585 and 1.995 or between 2 and 3 dbs. Therefore, the 1.66 is divided by 1.585, obtaining 1.047. Now, again noting column three, we see that 1.047 corresponds to a db ratio of .2; therefore, the 1 watt power level is equivalent to a db level of 20 plus 2 plus .2 or 22.2 db.

On the other hand, we may find in some manufacturer's literature that his amplifier has a power output of 32 db referred to a 6 milliwatt reference level. We wish to determine the actual power output of this amplifier in watts. From column three it is seen that a 30 dbs are equivalent to a power ratio of 1000, and that 2 dbs are equivalent to a power ratio of 1.585. Therefore, 32 dbs are equivalent to a power ratio of 1000 times 1.585 or 1585. This means that the amount of power represented by the 32 db level is 1585 times as great as the .006 watt reference. Thus, 32 dbs correspond to a power output of 1585 × .006, or 9.51 watts.

Perhaps it would be well to solve a few problems involving negative db levels so that the student may understand the process. Suppose that power is put into a telephone line at a level of +2 dbs. We will assume that the line produces a loss of 13 dbs. We now see one of the advantages of using the db notation. If the sending power is +2 db and the line loss is 13 db, then the power received at the far end of the line will be 2 - 13 or -11 dbs. We must next determine what amount of power in watts is equivalent to a level of -11 dbs. From column seven, we find that a db level of -11 is equal to a power of .00047 watt. Again, suppose that a microphone is rated as having an output of -43 dbs. What amount of power does this represent? Since the db level is negative, the amount of power will be less than .006 watt, or the -43 dbs represent a loss ratio. From column five, it is seen that a loss ratio of 40 db is equivalent to a power ratio of .0001, and that a loss of 3 db is equal to a power ratio of .5012. Therefore, the total loss ratio of 43 dbs would be equal to .0001 × .5012 or .00005012. This means that the power level of -43 dbs is only .00005012 times as much as the .006 watt reference. Therefore, -43 dbs are equal to a power of .006 × .00005012 or .00000030072 watt. This is .3007 microwatt.

Occasionally, it may be desirable to convert from one reference level to another. Suppose, for example, an amplifier is rated as having an output of 20 db referred to a 12.5 mw level. If it is desired to determine the db output of this amplifier when referred to a reference level of 6 mw, the procedure is to add 3.18 db to the db level as given. This would make the gain of this amplifier 23.18 db referred to a reference level of 6 mw. Likewise, when changing from the 6 mw level to the 12.5 mw level, 3.18 db are subtracted from the db level as referred to 6 mw. Thus, a power level of 15 db, referred to a 6 mw level would be 15 - 3.18 or 11.82 db when referred to a 12.5 mw level. The RCA Manufacturing Company rate their microphones in dbs as referred to the 12.5 mw level. A microphone rated at -75 db could have the rating changed to correspond to the 6 mw level by adding 3.18 db. When +3.18 db is added to -75 db, the new rating becomes -71.82 db.

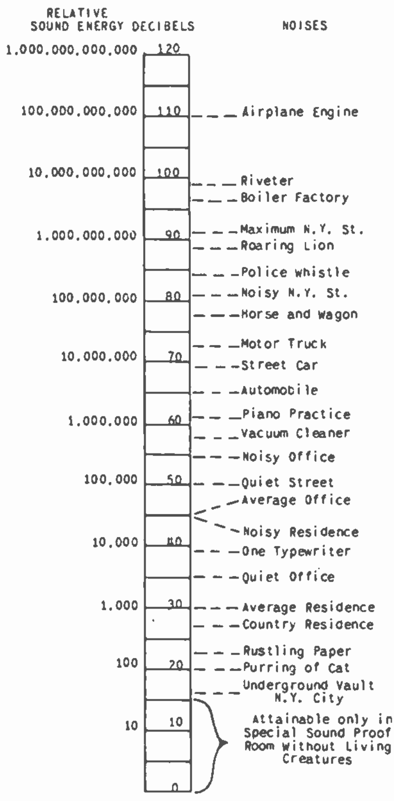


Fig.2 Sound level table.

5. SOUND ENERGY AND THE DECIBEL. The decibel unit is also used to designate various sound energy levels. In this application, the reference level equivalent to 0 db is ordinarily taken as 10^{-16} watt per square centimeter. This is the weakest sound that is usually detectable when the frequency is approximately 1000 cycles. At higher or lower frequencies, a greater amount of sound energy is necessary for the average person to hear it. Referred to this level, sound energy at the 55 db level would be 316,200 times as great or would be 31.6×10^{-12} watt. This is 31.6 micromicrowatts per square centimeter and is the average intensity of ordinary conversation. It should be realized that the acoustic power in deci-

bels or fractions of a watt have no direct connection with electrical powers expressed in watts or decibels. The decibel is used for sound energy merely because the ear has a logarithmic characteristic. Thus, it is not to be assumed that 10 db of electrical power is equivalent in any manner to 10 db of acoustic power. The accompanying chart (Fig. 2) shows the various sound levels encountered in everyday practice. It extends from 0 db, the threshold of hearing to 120 db, the threshold of pain, or the point at which the sound becomes uncomfortably loud.

6. USES OF THE DECIBEL. Let us now investigate some of the uses to which the unit decibel is put. The gain of practically all audio amplifiers is expressed in dbs, as well as the power output of the amplifiers. All microphones and phonograph pick-ups are rated in decibels. The volume indicator placed on the output of the audio amplifier which normally feeds a telephone line is graduated in decibels. This is merely a rectifier type AC voltmeter whose scale reads the power levels in dbs feeding the telephone line when it is placed across an impedance for which it is designed. When frequency response curves of audio amplifiers are made, the frequency is usually plotted against the power output of the amplifier in decibels. The reference frequency is ordinarily 400 cycles, and if, for example, it is stated that the output of the amplifier is down 3 db at 12,000 cycles, this statement means that the power output of the amplifier at 12,000 cycles is less than that at 400 cycles by 3 db. A loss of 3 db is a power loss ratio of approximately .5; and therefore, the output of the amplifier is one-half as much at 12,000 cycles as it is at 400 cycles.

If a few of the more common loss ratios are memorized, many conversions may be made without resort to a decibel table or logarithmic table. For example, it should be remembered that a loss of 10 db represents a power loss ratio of .1; that is, only .1 as much power is available after the original power has suffered a loss of 10 db. Likewise, a loss of 20 db reduces the power to .01 of its former value, and a loss of 30 db is equivalent to a loss ratio of .001. Also, it is not hard to remember that losses of 1, 2, and 3 dbs are loss ratios of approximately $\frac{4}{5}$, $\frac{2}{3}$, and $\frac{1}{2}$ respectively. Let us see how we may solve certain problems without using the table.

EXAMPLE 1: If a loss of 3 db represents a loss of one-half, how much loss is 6 db?

SOLUTION: A loss of 6 db represents two successive losses of 3 db. The first loss would reduce the power to one-half of its original value, and the second loss would further reduce the power to one-half of that remaining after the first loss. Thus, a loss of 6 db would be equivalent to a loss ratio of $\frac{1}{2} \times \frac{1}{2}$ or $\frac{1}{4}$; and so the original power would be reduced to $\frac{1}{4}$ its value, if it suffered a loss of 6 db.

EXAMPLE 2: What power ratio corresponds to a gain of 8 db?

SOLUTION: A gain of 8 db is equivalent to three separate gains of 3 db, 3 db, and 2 db. We have learned that the loss ratio of 3 db is $\frac{1}{2}$, and so the gain ratio is the reciprocal of this or 2.

Also, the loss ratio of 2 db is 2/3, and therefore the gain ratio is 3/2. Thus successive gains of 3 db, 3 db, and 2 db would be equivalent to gains of 2 × 2 × 3/2 or 6. Therefore, a gain of 8 db represents a power ratio of 6.

EXAMPLE 3. What is the power ratio corresponding to a gain of 23 db?

SOLUTION: A gain of 23 db is equal to a gain of 20 db and a gain of 3 db. The gain ratio of 20 db is 100 and that of 3 db is 2; therefore, a gain of 23 db is equal to a power ratio of 100 × 2 or 200. In a like manner, a gain of 33 db would be equal to a power ratio of 2000, etc.

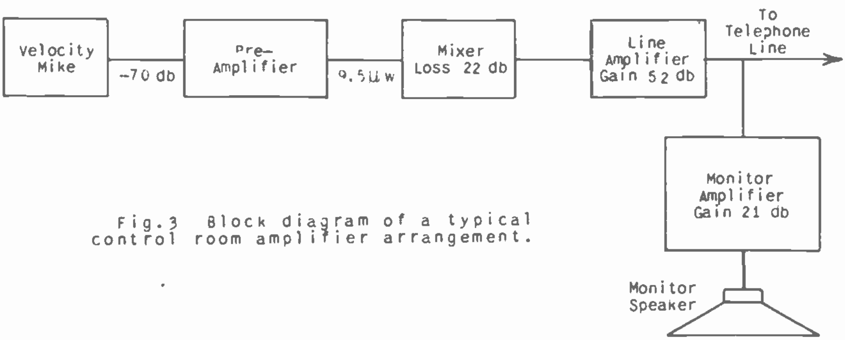


Fig.3 Block diagram of a typical control room amplifier arrangement.

Fig. 3 illustrates in block diagram form the audio equipment contained in the average radio station's control room. In this case, a velocity microphone having an output of -70 db is connected to a pre-amplifier whose power output is 9.5 microwatts. The pre-amplifier is connected to a mixing circuit which introduces a loss of 22 db, and it, in turn, is connected to a line amplifier with a gain of 52 db. The line amplifier feeds a telephone line which joins the control room with the transmitter. In addition, a monitor amplifier having a gain of 21 db is bridged across the telephone line, and its purpose is to amplify the signal to a level suitable for operating a monitor speaker.

From this information, we wish to calculate the following:

1. The output power of the microphone in microwatts.
2. The gain of the pre-amplifier in decibels.
3. The power input to the line amplifier in microwatts.
4. The db level into the telephone line.
5. The power output, in watts, of the monitor amplifier.

To make certain that the student becomes thoroughly familiar with the solving of decibel problems, we shall solve this problem step by step. The first item to be considered is the output of the microphone. This is -70 db, which, according to the table is equivalent to a power of .0000000006 watt, or a .0006 microwatt. The power output of the pre-amplifier is 9.5 microwatts, and the power ratio between the pre-amplifier's output and input is:

$$\frac{9.5}{.0006} = 15,833$$

From the table we see that this power ratio is between 40 and 50 db. By calculation, using the method previously explained, we find that the db gain is 42.

The power into the mixer is 9.5 microwatts and it causes a power loss of 22 db. This, as may be found from the table, is equal to a loss ratio of .00631. Therefore, the power out of the mixer or into the line amplifier is .00631 × 9.5 or .06 microwatt.

The db level into the telephone line is found as follows: The output of the microphone is -70 db and the gain of the pre-amplifier was calculated as 42 db. Therefore, the db level out of the pre-amplifier is -70 plus 42 or -28 db. The mixer causes a loss of 22 db which brings the db level down to -50 db; this is the level at which the signal is fed into the line amplifier. The line amplifier produces a gain of 52 db, and this brings the signal level up to +2 db, which is the level at which it is fed into the telephone line.

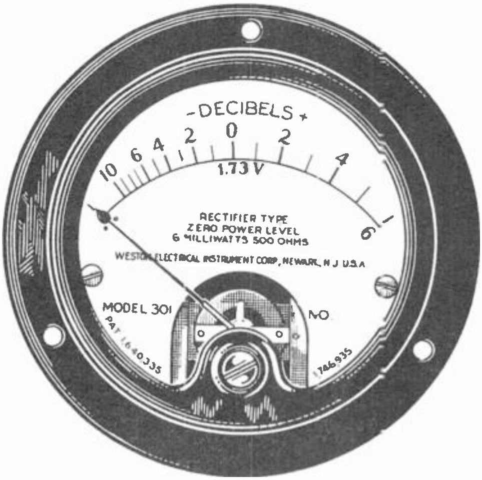


Fig.4 A volume indicator meter calibrated in decibels.

The gain of the monitor amplifier is 21 db, and therefore the db level into the speaker is 2 plus 21 or +23 db. This, as may be calculated from the table, is equivalent to a power ratio of 199.5. Therefore, the power output corresponding to this level is 199.5 × .006 or 1.197 watts.

The foregoing illustrations should demonstrate most conclusively the great utility of the decibel unit. In fact, new uses for this unit are being discovered every day. It is now common practice to use decibel meters to determine various power levels. These meters are merely rectifier type alternating current voltmeters.

Naturally, they are correct only when connected across an impedance for which they are designed. Since many lines have an impedance of 500 ohms, most of these meters are designed for this impedance, and their dial readings are correct when they are connected across a line of this impedance. Fig. 4 illustrates one of these meters. Such a meter is found in every broadcast station control room. It is used to determine the power being fed into the telephone line which carries the audio to the transmitter. The telephone company will not allow more power than 0 db. or +2 on peaks to be fed into the line, because more than this amount of power is liable to cause interference with other lines contained in the same cable. It is, of course, desirable that the amount of power being transmitted be as near this limit as possible, since it will then be large compared to the natural noise which is picked up by the line. To enable the operator to keep the power level as near the maximum allowable as possible, the db meter or volume indicator should be fast acting so that it will be able to follow the peaks contained in the audio signal.

Notice from Fig. 4 that the number 1.73 v is printed on the dial. This is the R.M.S. voltage which must be developed across an impedance of 500 ohms to produce a power of 6 milliwatts corresponding to a level of 0 db. This voltage sets up a current of 3.46 ma. in the 500 ohms.

The volume indicator meter, or as it is more often called, the V,I. meter, may be either fast acting or slow acting. If it is to be used to determine the attenuation constant or frequency response of a telephone line, it is immaterial whether the meter has a fast action or not. In this case, the signals will be single frequencies of constant amplitude and the needle of the meter will come to rest indicating the db level at the output of the line. On the other hand, when speech or music is being fed into a line, the needle of the meter will fluctuate rapidly in direct accordance with the many variations of the complex wave which represents the signal. A fast acting meter will be better able to follow the many peaks in the program which a slower acting meter might miss. A fast meter, however, is hard to follow, and monitoring a program with such an instrument is very tiresome. Naturally, a slow acting meter is equally undesirable, since many peaks pass into the line which are not indicated on the meter. Thus, a compromise is usually effected, and a meter is employed which is neither too fast nor too slow.

PART TWO--MICROPHONES

6. REQUIREMENTS OF A MICROPHONE. The purpose of the microphone is to convert the acoustical energy provided by speech or music into electrical energy of corresponding wave form. The acoustical energy is set up in the form of compressions and rarefactions in the air. If the resulting electrical current issuing from the microphone varies in direct accordance with the changes in the air pressure, the fidelity of the microphone is perfect. Actually, no microphone has such an ideal characteristic. All suffer more or less from frequency distortion, although nearly all used in modern broadcast stations have a response the fidelity of which is consistent with the fidelity of the amplifiers with which they are used. The so-called high-fidelity type of transmission allows the passage of all frequencies in the range of 30 to 10,000 cycles. This demands that the transmitter, the modulator, all the audio amplifiers and the microphone have a response at least this near perfect. All this equipment, must, of course, not only pass these frequencies, but the response curve of output plotted against frequency must be essentially flat within this range.

In addition to having an excellent frequency response, a high quality microphone must be capable of responding to a large amount of pressure variation without distortion. The loudest sound to which a microphone is subjected may be thousands of times as great as the weakest sound to which the microphone is sensitive. Unless the microphone is capable of converting this wide range of acoustical energy into electrical energy without producing distortion, the quality of the audio system will suffer.

Some microphones have a tendency to produce a background noise such as a hissing or sputtering. Unless this noise voltage set up by the microphone is very low, it will be audible when the studio sounds being picked up are somewhat weak or during the times that no sound is being introduced into the microphone. It has been determined that for this background noise to be inaudible, it must be 40 db below the weakest sound to which the microphone is expected to respond.

7. THE CARBON MICROPHONE. The earliest microphones that were used for broadcasting were the so-called single-button carbon micro-

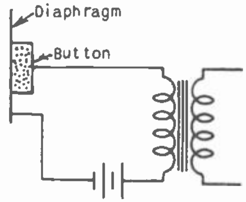


Fig.5 A single-button carbon microphone and its battery circuit.

phones. They were exactly the same as are now employed in telephone instruments. The original idea of the carbon microphone was conceived by Thomas A. Edison shortly after Bell had introduced the telephone. In construction, they consist of a thin metallic diaphragm which vibrates as the sound waves strike it. To the rear of the diaphragm there is attached a small chamber containing many carbon granules. This is known as the microphone button. The microphone is always used in connection with a battery, which is connected as shown in Fig. 5. It is seen that the current from the battery flows through the granules of carbon and then through the primary of an audio transformer. When no sound is actuating the diaphragm of the microphone, the current supplied by the battery is constant.

Now, when the diaphragm is set into motion by the variations of the pressure in the sound wave, the carbon granules are first squeezed together and then released. When they are pressed close together, they make better contact with each other, and the resistance of the button is decreased. This, of course, causes the current supplied by the battery to increase. When the diaphragm moves outward from its normal position, the pressure on the button is released and the carbon particles make poorer contact with each other. This results in an increase of the resistance of the button, and the current supplied by the battery falls to a value less than normal.

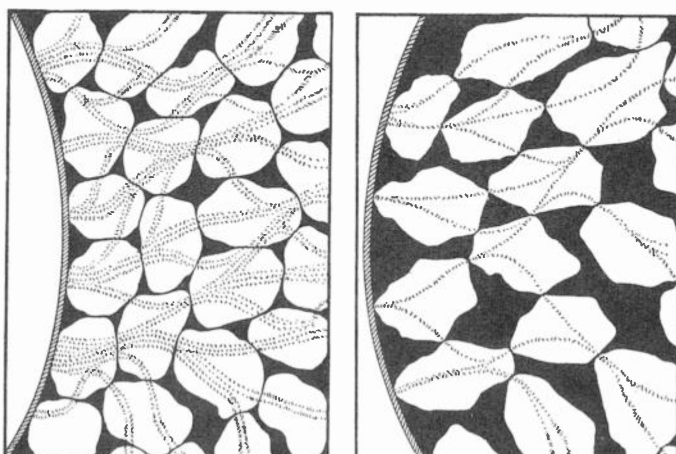


Fig. 6 (A) An enlargement showing the grains of carbon in a microphone when the diagram is compressed. (B) Illustrating how the resistance of the carbon button increases when the diaphragm is released.

And so, as a person speaks into the microphone, the variations of the sound waves cause the diaphragm to vibrate in exact accordance, and the resistance of the button does likewise. This sets up a varying current in the battery circuit and through the primary of the audio transformer whose variations correspond with the changes in pressure of the sound wave. Across the secondary of this transformer there is produced an alternating voltage containing these sound wave variations, and this voltage may be applied to the grid circuit of a tube for amplification. Fig. 6 shows an enlarged drawing of the diaphragm and the carbon granules contained in the button. At A, the diaphragm is bent inward and the carbon grains are tightly packed. At this time the resistance is low as is evidenced by the many current paths which are formed. (The current paths are shown in dotted lines.) At B, the diaphragm has moved outward and the carbon grains are loosely packed. In this case, the current paths are few and the resistance of the button is high.

The advantage of the single-button microphone is that it is extremely sensitive and has a comparatively large output voltage. In fact, when it is used in a telephone instrument, the signal currents may be sent several miles without amplification, and the energy received at the far end is easily able to operate a telephone receiver. The disadvantage which prevents its use in broadcast practice, is the fact that its frequency response is exceptionally poor; both high and low frequencies are lacking. This fault was recognized early as broadcasting increased in popular favor, and the next step forward in the production of a better microphone led to the development of the double-button carbon microphone.

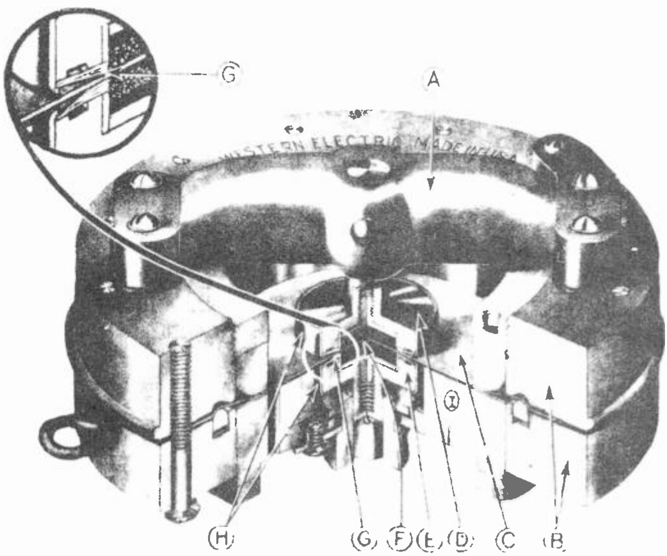


Fig. 7 Showing the construction of a double-button carbon microphone.

The double-button carbon microphone, a diagram of which is shown in Fig. 7, has a thin duraluminum diaphragm (C) which is .00017 inch thick. This is stretched very tightly in front of a flat metal plate (I) from which it is separated by .001 inch. By stretching the diaphragm in this manner, its natural period of vibration is made very high (approximately 6,000 cycles). This frequency was above the audio range transmitted at the time that the double-button carbon microphone was popular. With the resonant frequency above the transmitted audio range, the blasting which would occur if a tone of the natural frequency of the diaphragm were to be picked up by the microphone is avoided.

Placing the diaphragm close to the flat metal plate causes a high damping effect due to the compression of the air between the diaphragm and the plate. Two metal rings (B) form the frame of the microphone and also provide the stretching tension on the diaphragm.

Two brass cups (E) and (D) are placed one on each side of the diaphragm. These cups are separated from the diaphragm by the felt gaskets (G). The cup (D) is supported by the arm (A), and the cup (E) rests on the flat metal plate (I). These brass cups are nearly filled with fine carbon granules. The granules are in the form of polished balls of such a size that they will pass through a screen having sixty meshes per inch. Each button contains approximately three thousand of these granules. It is customary to gold plate each side of the diaphragm at the point where the carbon granules make contact. This provides a better electrical connection between the buttons and the diaphragm. The diaphragm is connected to the frame of the microphone and is the common connection for both buttons. The arm (A) is insulated from the frame of the microphone and is one terminal of the microphone which connects to a button. The other terminal is at the rear of the microphone and it connects to the other button.

Fig. 8 shows a double-button carbon microphone connected to an amplifying stage. We shall assume that button (D) is on the exposed side of the diaphragm. It may be seen that a direct current flows through the microphone at all times when the switch S

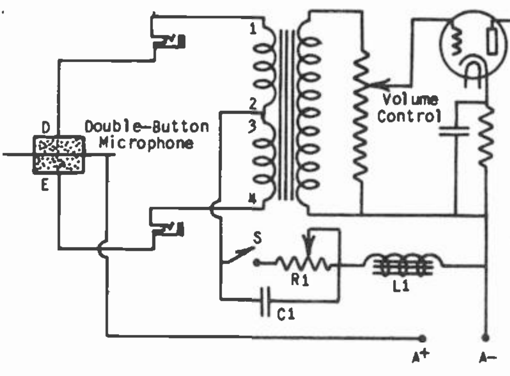


Fig.8 A double-button carbon microphone connected to the input of an amplifier.

is closed. The current is supplied by the battery (A) which also furnishes filament voltage for the amplifier tube. The resistance (R_1) regulates the amount of current that flows through the buttons. This should not exceed 25 ma. per button. Separate jacks are provided so that each button current may be measured independently of the other. Each button has a resistance of approximately 100 ohms. and the transformer must be of the proper turn ratio to match the microphone to the grid circuit of the vacuum tube.

As the sound waves strike the diaphragm, the compressions cause it to move away from button (D) and toward button (E). Thus, the carbon granules in the top button are released and those in the bottom one are compressed. The resistance of the top button increases and that of the bottom one decreases. This causes the current through the top button and through the top half of the primary of the transformer from points 1 to 2 to decrease, and that through the bottom button and the lower half of the primary from points 3 to 4 to increase. Since a rarefaction follows the pressure wave, the diaphragm will be bent outward from its normal position, and this action will cause the current through the top button and through the top of the primary to increase, while at the same time the current through the bottom button and the bottom half of the primary will decrease. It may, therefore, be seen that the action of the double-button microphone is very similar to that of a push-pull stage. As the current through one button increases, that through the other button decreases and vice versa.

The sensitivity of the double-button carbon microphone is not very great; that is, it has a fairly low output voltage and some amplification must be employed. However, the fidelity of this type of microphone is much better than that of the single-button type. The push-pull arrangement of the buttons balances out effectively any even harmonics which a non-linear relationship between the changes in the resistance of the buttons and the variations in the sound wave might produce.

Ordinarily, carbon microphones are energized by a battery of from 4 to 12 volts, and the current regulating resistor R is approximately 400 ohms. Changing the size of the battery has no effect on the magnitude of the secondary voltages since these depend only on the changes of current. It is to be noticed that the direct current through the buttons flows through the two halves of the primary in opposite directions so that there is no saturation of the core of this transformer. A filter circuit consisting of the

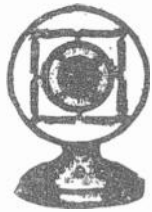


Fig.9 Showing the method of mounting a carbon microphone to avoid mechanical vibration.

inductance L1 and the capacity C1 is included in the circuit. This filter protects the microphone from surges in current when the switch S is opened. A surge of current through the microphone buttons or allowing too much DC current to flow through the microphone at any time will cause the carbon granules to pack. There is a certain amount of power which the buttons of the microphone must dissipate. If the current becomes excessive, due either to too low a regulating resistance or to a current surge produced by opening the switch, the large current which flows through the carbon granules causes small sparks and arcs between them which literally welds them together. This action greatly lowers the resistance of the microphone and causes serious impairment of its sensitivity.

If packing occurs, the remedy is to disconnect the current, and then gently tap or agitate the microphone. The microphone should never be tapped or jarred in any manner when current is flowing through it. Moving the microphone while the current is turned on often causes packing of the carbon granules, which, if severe enough will render the instrument inoperative. To prevent vibration, the microphone is usually placed in a spring suspension mounting as shown in Fig. 9. If a microphone becomes so packed that tapping it will not loosen the carbon granules, it is evident that rust spots have formed on the grains of carbon and the only remedy is to send the device back to its manufacturer for repacking with new carbon.

Even in ordinary operation, there are usually tiny intermittent arcs between the carbon grains which, although they may not be great enough to cause the buttons to pack, will produce a hissing noise which is amplified along with the voice currents. This hissing and sputtering sound is characteristic of the carbon microphone and is the one reason that it is no longer used in broadcast stations or in high-quality public address systems.

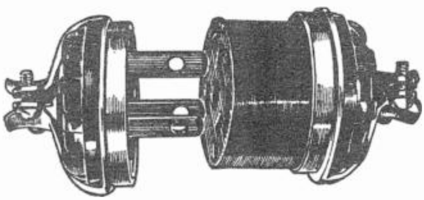


Fig. 10 A microphone plug.

The ordinary double-button carbon microphone has an output level of approximately -45 db referred to a 6 milliwatt level, and will require about three stages of amplification to bring the level up to a point suitable for introducing it into a telephone line for transmission to the transmitter. A three-prong plug connects the microphone to the proper receptacle in the studio. This plug and socket are so arranged that it is impossible to make the wrong connection between the plug and the socket. One of these plugs is shown in Fig. 10. The offset prong is always the frame or ground connection, while the other two prongs connect to each of the carbon buttons.

8. THE WESTERN ELECTRIC DYNAMIC MICROPHONE. The dynamic microphone is founded on the same principle as the dynamic loud speaker. In the dynamic speaker a voice coil is floated in an intense steady magnetic field, and through this voice coil flow audio currents. The magnetic field created by this current interacts with the steady field and produces a force which causes the cone to which the voice coil is attached to vibrate in direct accordance. Thus, the cone produces sound waves corresponding in their variations to the changes in the current flowing through the voice coil. The only difference between the dynamic microphone and the dynamic speaker is that in the former, the sound waves cause a diaphragm to vibrate which, in turn, moves a coil rigidly attached to the diaphragm. This coil moves through an intense magnetic field produced by a permanent

magnet, and this action induces voltages in the coil which correspond exactly with the vibrations of the diaphragm.

There are illustrated in Fig. 11, the constructional details of the original dynamic microphone manufactured by the Western Electric Company. The diaphragm is made of thin duraluminum and has a dome-shaped center portion which extends to the inner edge of the moving coil. This stiffens the center of the diaphragm and insures that it will vibrate substantially as a plunger throughout the fre-

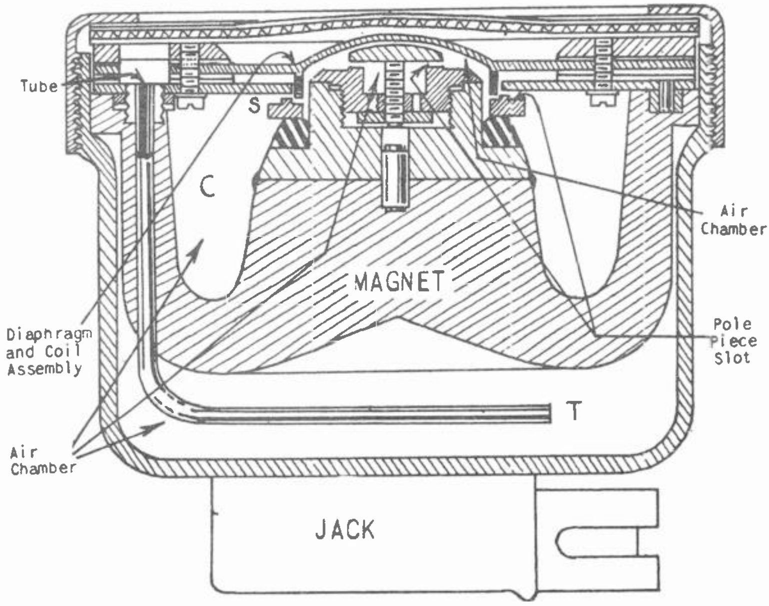


Fig.11 Cross section of a dynamic microphone.

quency range that is to be transmitted. The moving coil is composed of several turns of aluminum ribbon wound on edge. The ribbon is insulated from itself and from the diaphragm by a coat of varnish, which also serves to hold the coil to the diaphragm. After the varnish has been applied, the assembly is baked to assure a rigid bond between the coil and the diaphragm.

To provide the intense magnetic field, a permanent magnet of cobalt steel is used. This material has such properties that the size and weight of the magnet can be reduced to a minimum and the magnet retains its qualities for many years. The pole pieces are of soft iron; the inner pole piece is welded to the central portion of the permanent magnet and the outer pole piece is secured in correct alignment by two pins which fit into soft iron inserts in the cobalt steel magnet.

The diaphragm is protected from mechanical injury by means of a perforated metal screen which is covered by a screen of silk, the purpose of which is to prevent dust and particles of magnetic material from accumulating on the diaphragm. The metal screen and metal housing that encase the microphone are insulated from both moving coil and diaphragm and together form a shield which may be connected to ground through one of the three contacts on the jack located in the back of the microphone housing. The two outside contacts of the jack connect to the moving coil. A locking device is provided to assure that positive contact is made between the jack and the microphone plug and, in addition, to prevent the plug from being accidentally withdrawn from the jack while the microphone is in use.

The chamber C and the narrow slit construction S, together form an acoustical compensating system which tends to make the voltage generated in the moving coil independent of the frequency. Such a construction is necessary because the output of the microphone will not be flat throughout the audio range since the natural mechanical resonant frequency of the diaphragm will tend to make the output of the microphone greater at this natural frequency. The tube T is also a part of this acoustical compensating system.

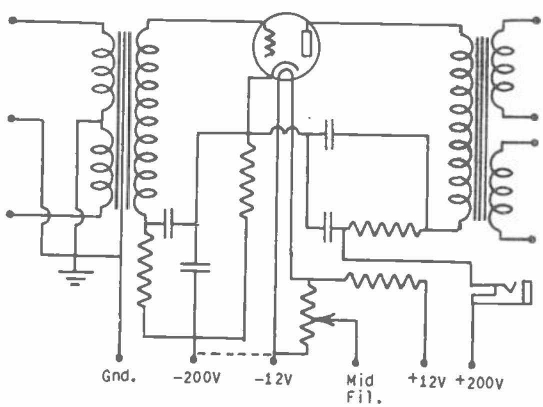


Fig.12 A pre-amplifier for a dynamic microphone.

With careful design and selection of materials, the operation of the microphone will be practically independent of variations in temperature, barometric pressure or humidity, that are likely to be encountered in normal use. The impedance of the moving coil in this microphone is approximately 35 ohms and, for that reason, a coupling transformer is not necessary in the microphone case. The microphone can be connected by comparatively long lines (up to 100 feet), directly to the main control room of the broadcasting station. A pre-amplifier for a microphone of this type is illustrated in Fig. 12.

The output level of the dynamic microphone is considerably less than that of the carbon microphone. This power level is approximately -50 db, but may, under extreme conditions be as low as -90 db and, because of the low impedance of the moving coil, a very high grade contact is necessary at the detachable connection between the microphone and the amplifier. To provide this, a special plug and jack are used. Three contacts are required, so the plug is equipped with three flat prongs, each of which fits between double clips in the jack. Positive contact is obtained by applying heavy pressure to a cam lever on one side. The cam lever fits snugly on one

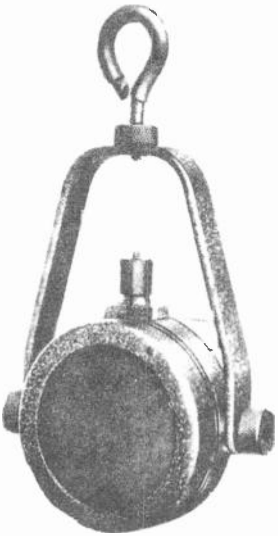


Fig. 13 A photograph of the Western Electric dynamic microphone.

side of the plug when it is in the closed position. The two outside connections are for the moving coil while the center connection is to ground the case of the microphone. A photograph of a Western Electric dynamic microphone of the hanging type is illustrated in Fig. 13.

9. THE RCA INDUCTOR MICROPHONE. The inductor type of microphone which was designed by the RCA Manufacturing Company, operates on the same principle as the dynamic microphone. A drawing illustrating the construction of this type of microphone is shown in Fig. 14. C is the outside case of the microphone which is made of brass and is finished in a bronze color. E is a wire screen which covers the diaphragm D. The diaphragm proper is made of thin aluminum and is approximately $\frac{1}{4}$ inch wide and 2 inches long. It is slightly concave, which adds to its rigidity. The supporting edge of the diaphragm is corrugated in order to secure the proper value of elasticity. The corrugations are shown at B in Fig. 14. The conductor in which the voltage is generated is at A. It is approximately 2 inches long and $\frac{1}{100}$ inch in diameter. It is coupled rigidly to the diaphragm by means of a V-shaped glassine paper structure.

The use of the straight conductor makes possible the design of an extremely efficient magnetic circuit. The leakage flux in this design is very low, the strong magnetic field being secured by a cobalt steel magnet, with its poles marked N-S in the figure.

Electrical resistance of the moving conductor is approximately .07 ohm and a transformer must be provided to match this to a 250 or a 25 ohm line. This transformer, as may be seen, is mounted within the open portion of the horseshoe magnet. The extremely small size of the coupling transformer is made possible by the fact that no direct current flows through it. Also by use of a special quality of steel, excellent results are possible, even with such a small size.

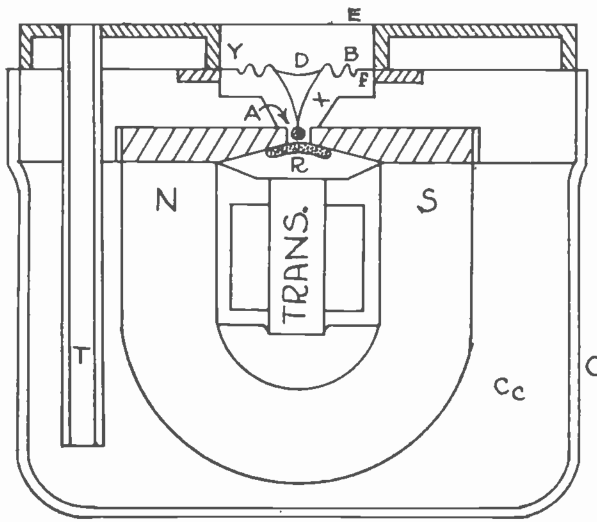


Fig.14 The construction of the RCA inductor microphone.

The operation of the microphone is as follows. The sound waves strike the diaphragm D, cause the conductor A to vibrate between the north and south poles of the permanent magnet. This causes an audio voltage to be generated within the conductor. The conductor is connected to the primary of the output transformer and the impedance is properly matched from .07 ohm to 250 ohms. From there the output is connected to the input of a pre-amplifier.

Again, as in the case of the dynamic microphone, various compensating devices are used to insure that the output of the microphone will be practically flat throughout the useful audio range. The frequency response of this microphone compares very favorably with that of the dynamic type of microphone except that the useful range of the inductor type of microphone is purposely limited at 60 cycles. This feature will assist greatly in the elimination of noise due to wind and allows the microphone to be used out of doors under adverse conditions. The output of the inductor microphone is approximately -64 db.

10. THE EIGHT BALL AND SALT-SHAKER MICROPHONES. Both the Western Electric dynamic and the RCA inductor types of microphones have been superceded by other types which have better frequency response and are more desirable for general broadcast use. About 2 years ago, Western Electric introduced the 630-A dynamic microphone, a photograph of which appears in Fig. 15. Due to its spherical shape, small size and black coating, it was immediately nicknamed the "eight ball". It has excellent frequency response and has become quite popular in broadcast studios. One feature of the eight ball microphone which makes it particularly valuable for certain uses is the fact that it is non-directional in its response. This eliminates the necessity of studio artists crowding together on one side of the microphone.

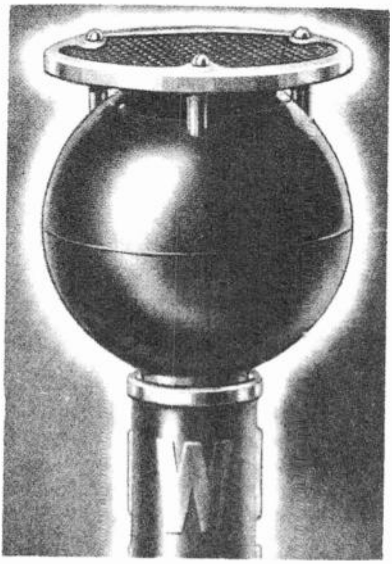


Fig.15 The Western Electric "Eight Ball" microphone.

Approximately one year ago, the Western Electric Company introduced another type of dynamic microphone, a photograph of which is shown in Fig. 16. Due to its shape and appearance, it has come to be called the "salt-shaker" microphone. Its true type number is 633-A. It is made in the shape of a cylinder, is 2 inches in diameter, 3 inches long and has a perforated shield forming a cap at one end. It may be used in three different positions, desk stand, floor stand, or hung by the speech cable. It has one other decided advantage in that it may be used either as a non-directional microphone or one having directional characteristics. This conversion is accomplished by placing a small directional baffle over the top of the microphone. The microphone with this baffle attached is shown in Fig. 17. In the non-directional position without the baffle, the microphone's response is fairly balanced around an output level of -90 db throughout the entire range of 40 to 10,000 cycles. With the baffle attached and the microphone tilted to the directional position, it has an increase in sensitivity in the range of 1,000 to 3,000 cycles, a factor which tends to make speech sound more natural, as many tests have indicated that this is the region most suited for intelligibility of speech.

Fig.16 The western Electric "Saltshaker" microphone.

The salt-shaker is being widely used, not only by broadcast studios, but also for public address work and for every application demanding a quality microphone of popular price. Its directional baffle makes it ideal for broadcasting various sports events and gatherings of all kinds where background noise and the like may be minimized by merely pressing the directional baffle in place.

Fig.17 The saltshaker microphone with the directional baffle in place.

Many broadcast stations are using this microphone for remote pickups as it is quite rugged and is able to stand considerable abuse. The salt-shaker microphone has a low electrical impedance and it may be used at a considerable distance from the amplifying equipment. The housing is finished in aluminum gray and the weight of the microphone is only 10 ounces.

11. THE VELOCITY MICROPHONE. A schematic diagram of the velocity, or as it is sometimes called, the "ribbon" microphone, is shown in Fig. 18. A very light ribbon of corrugated aluminum R

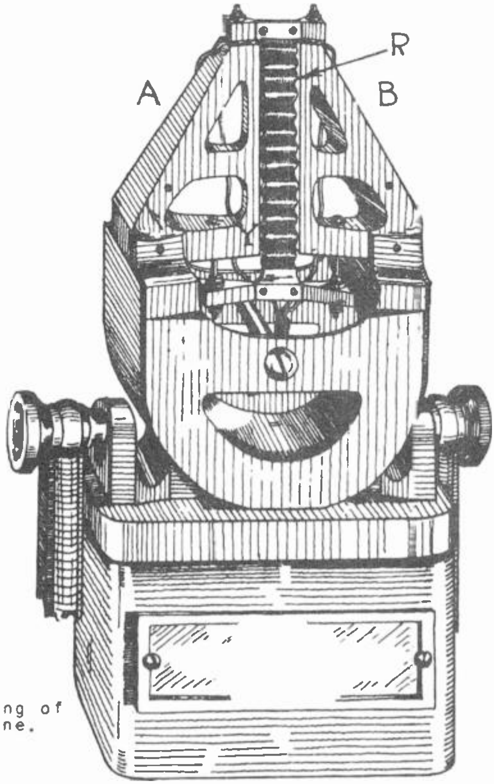


Fig. 18 An outline drawing of the RCA Velocity microphone.

hangs loosely between the pole pieces of a powerful cobalt steel magnet (A and B) in such a position that the magnetic field cuts through the edge of the ribbon. The ribbon may move back and forth between the pole pieces without touching them, although the air clearances are small so that the field strength will be kept as high as possible.

Unlike other types of microphones, the velocity microphone does not depend for its operation upon the actual pressure of the sound wave, but, instead upon the differences in pressure between the front and back sides of the ribbon. Such a movement is proportional to the velocity of the air molecules which, in vibrating, transmit sound waves. As the ribbon vibrates between the pole pieces, due to the effect of a passing sound wave, there is generated within the ribbon a voltage which varies in both amplitude and frequency in direct accordance to the changes of the sound wave. The resistance of the ribbon is, of course, a fraction of an ohm. This output is transferred immediately to the primary of a matching transformer located in the base of the microphone.

The output of the velocity microphone varies from -68 db to -100 db for different types of these instruments. The broadcast type has a relatively low output, but has excellent frequency response. The curve obtained by plotting the output against the frequency is practically flat from 20 to 15,000 cycles. This is true, provided the sound source is at least 2 feet from the microphone. With the sound source nearer to the microphone, the lower notes are accentuated excessively and some distortion occurs. Thus, this type of microphone, while excellent for music and certain other types of pickup, is not as well suited for speech as some of the other varieties.

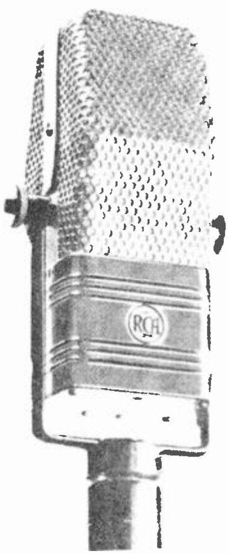


Fig.19 A photograph of the RCA Velocity microphone.

Since the ribbon hangs directly between the pole pieces of the permanent magnet, it is acoustically shielded on two sides by the pole pieces, but is free to receive sound impulses on either of its broad surfaces. Thus, the velocity microphone is equally sensitive from front or back, but is practically dead at the sides. This bi-directional characteristic is often valuable in helping to avoid acoustical feedback from the loud speaker to the microphone in public address installations.

The ribbon is exceptionally delicate, and must be protected from strong drafts or puffs of wind. To accomplish this, it is surrounded by an inner and outer screen of fine mesh silk attached to its magnetic assembly and outer case. These, together with a metallic screen aid in protecting the microphone against mechanical injury or against accidental entry of magnetic material into the assembly.

The type 44-B velocity microphone which is manufactured by the RCA Manufacturing Company is the one ordinarily used in broadcast practice. A photograph of this microphone is shown in Fig. 19. RCA also manufactures a Junior velocity microphone of popular price for public address work. Perhaps the most interesting velocity microphone produced by RCA is the lapel type, an illustration of which appears in Fig. 20. This microphone clips directly upon the

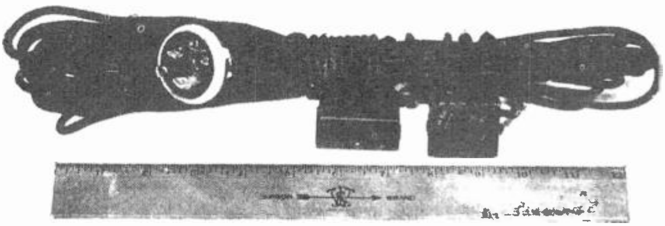


Fig.20 The RCA lapel type velocity microphone.

lapel of the speaker and thus enables him to move backward and forward and still have his voice picked up by the microphone. The microphone itself is slightly smaller than a matchbox and weighs only $3\frac{3}{4}$ ounces. It is connected to a matching transformer of similar weight which is carried in the speaker's coat pocket. The connecting cable is 39 feet long, thus giving the speaker a wide radius of action.

12. THE RCA UNI-DIRECTIONAL MICROPHONE. Practically speaking, there is no such thing as an all-purpose microphone. In some instances, a non-directional microphone is desirable, and in others

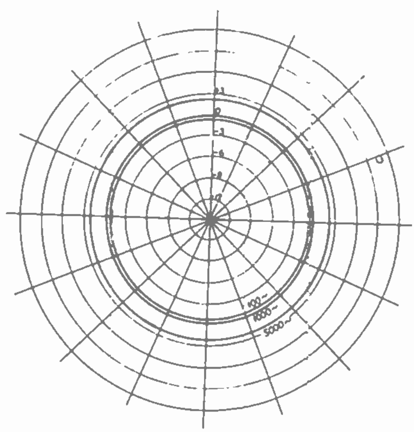


Fig.21 Response characteristic of a non-directional microphone.

a microphone having such characteristics that it responds to sound striking it from just one direction has many advantages. Before discussing the construction of the uni-directional microphone, let us determine just what is meant when it is said that a certain microphone is non-directional, bi-directional, uni-directional, or semi-directional.

A microphone that is truly non-directional responds equally well to sound waves striking it from any angle. Further, the microphone is equally non-directional for low frequencies, frequencies in the middle range, and high audio frequencies. To show clearly the directional characteristics of a microphone, it is common practice to plot a polar diagram which gives the sensitivity of the microphone in all directions for several frequencies in the audio range. A diagram of this type for a non-directional microphone is illustrated in Fig. 21. The various concentric circles are graduated in dbs and the sensitivity at 1,000 cycles is taken as 0 db or the reference level. From this diagram, it may be seen that at 5,000 cycles, the output of the microphone is +3 db and at 100 cycles, it is just under 0 db. Notice that the response of this microphone is truly non-directional for all three of these frequencies.

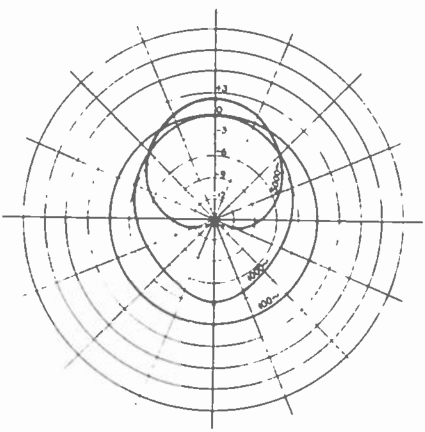


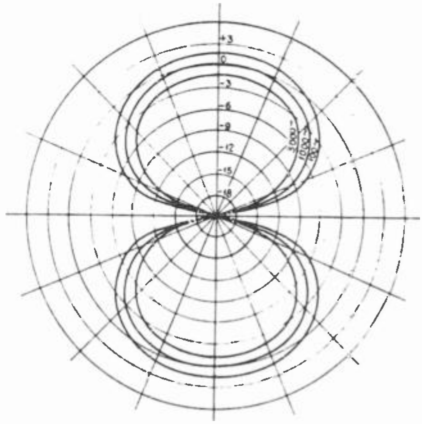
Fig.22 Response of a semi-directional microphone.

The semi-directional microphone is one which is really non-directional for a low frequency sound and is highly directional for a high frequency sound. A polar diagram of such a type is illustrated in Fig. 22. Notice that at 100 cycles, the response of the microphone is non-directional. At 1,000 cycles, the response is nearly non-directional, while at 5,000 cycles, the back side of the microphone is practically dead. At an angle of 90° from the front of the microphone, the response to a 5,000 cycle frequency is only -6 db compared to 0 db for a sound directed toward the face of the microphone.

The velocity microphone discussed in the preceding section is bi-directional and has a characteristic, such as the one illustrated in Fig. 23. The characteristic has the form of a figure 8 and indicates that the microphone is sensitive from either its front or back, but is practically dead at the sides. Also, note that the directional characteristics are practically the same for a low or a high frequency sound.

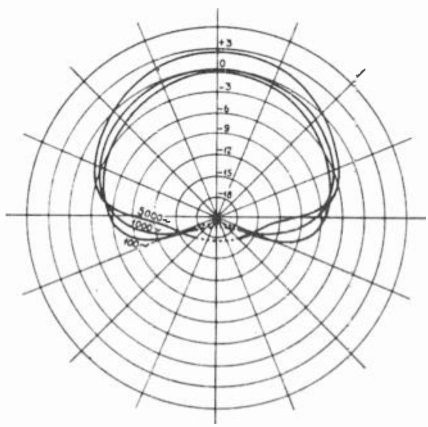
Finally, we come to the truly uni-directional microphone which

Fig.23 The response of a bi-directional microphone.



has a response such as shown in Fig. 24. It is seen that this microphone is practically dead for all sounds, regardless of frequency, striking its back side. Such a characteristic is very desirable in

Fig.24 The response of a uni-directional microphone.



some applications, as it prevents pickup of extraneous noise. The front side of the microphone has a very uniform response, while on the back side, sounds are attenuated approximately 20 db. It may be placed with its dead side toward an audience and thus eliminate practically all noise, while at the same time, the wide angle of pickup on the front side will cover a whole stage. Another advantage, especially in small studios is that it may be placed much closer to a wall than any other type of microphone, since the sound which is reflected from the wall will have relatively little effect upon the dead side.

A photograph of the RCA 77-A uni - directional microphone is shown in Fig. 25. The case removed to show the internal construction may be seen in Fig. 26. A most ingenious arrangement is used

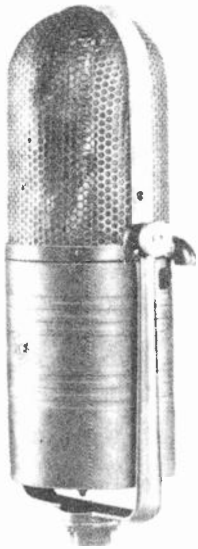


Fig. 25 Photograph of the RCA Uni-directional microphone.

to provide the uni - directional property of this microphone. In other velocity microphones, the ribbon is entirely free, but in this instance, it is rigidly clamped at the center and the upper

Fig. 26 The uni-directional microphone with the cover removed.

half of the ribbon is enclosed at the rear, a feature which produces the uni-directional characteristics.

Before discussing the operating principle of the uni-directional microphone, let us inquire as to just what factors cause a microphone to have directional characteristics. It may be proved that, theoretically, all microphones of the diaphragm type are non-directional. It is, of course, true that the diaphragm microphone does exhibit some directional qualities, and it might seem, upon first thought, that the directionalism of the diaphragm microphone at high frequencies indicates a tendency toward single-sidedness. Such a tendency, however, is found, upon examination, to be due to the distortion of the sound field by the solid surface of the microphone. This phenomenon is more apparent at high frequencies, because the dimensions of the surfaces are comparable to the wavelengths of the high frequency sound and so all microphones of the

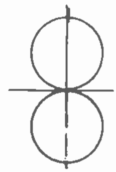


Fig.27 The response of the lower part of the ribbon of the uni-directional microphone.

diaphragm type are fundamentally non-directional and would be, in practice, if they could be made sufficiently small so that they would not seriously distort the sound field.

On the other hand, all microphones operating upon the velocity principle are bi-directional in that they are equally responsive from both the front and back of the microphone and practically dead at the sides. Thus, Figs. 27 and 28 illustrate the responses of the ribbon or velocity type of microphone and of the pressure or diaphragm microphone respectively. The uni-directional characteristic is produced by combining the responses of each type of micro-

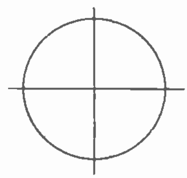


Fig.28 The response of the upper part of the ribbon of the uni-directional microphone.

phone. The response of the non-directional pressure-actuated part may be represented by a circle with its center at the microphone and that of the bi-directional velocity-actuated part by two circles tangent to the microphone faces.

The fact that the upper half of the ribbon is enclosed at the rear causes it to operate upon the pressure principle, while the lower half of the ribbon, being open at both front and back operates entirely upon the velocity principle. Considering Fig. 27, one of the circles representing the response of the bi-directional part of the microphone is in phase and adds to the non-directional circle while the other lobe of the velocity part is in opposite phase and hence subtracts. The resultant response is represented by a curve such as the one illustrated in Fig. 29 and, as may be seen, provides a very satisfactory degree of directionalism. It must be understood, of course, that these are idealized patterns; however, in practice the predicted results are closely approached. The force causing the lower half of the ribbon to vibrate is the difference between the varying pressure in front of the ribbon and the varying pressure behind it, or in other words, the pressure gradient or change in pressure with distance in the sound wave itself. The upper half of the ribbon, being enclosed at the rear,

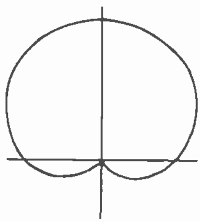


Fig.29 The combined response of the two parts of the ribbon in the uni-directional microphone.

depends for its motion upon the difference between the varying pressure in front of the ribbon and the static pressure behind it. In other words, its movement is proportional only to the instantaneous pressure of the sound wave and it is therefore a true pressure microphone. Merely enclosing the space in back of the ribbon is not sufficient for such an action causes the trapped air to exercise a damping effect which would depend upon the frequency and, thus the response would vary with frequency and also the directionalism. This is avoided by connecting a tube at the back of the upper half of the ribbon, allowing the other end of this tube to enter an acoustical labyrinth, lightly packed with sound absorbing material.

13. THE PIEZO ELECTRIC PRINCIPLE AS APPLIED TO MICROPHONES. The piezo electric properties of certain types of crystals was discussed briefly in Lesson 2 of Unit 3. At that time, the statement was made that a crystal of Rochelle Salts was, by far, the most active of any common piezo - electric crystal. Rochelle Salts is not used for frequency control purposes, since it is subject to the effect of humidity and temperature. Although Rochelle Salts are soluble in solution, extensive experiments have indicated that suitable protection against moisture and humidity can be obtained by enclosing the crystals in waterproof papers and waxes. In fact, actual tests of the crystal microphone showed that the crystal was not affected by moisture, even after hours of immersion in water.

A crystal of Rochelle Salts as grown commercially has a rough surface or base on which it is grown and has half the number of possible crystalline faces. The resulting crystal is clear, transparent and homogeneous. It has the shape illustrated in Fig. 30. Notice from this figure that the crystal has three axes, each at right angles to the other two.

Rochelle Salts crystals manifest many unusual properties. For example, if a plate is cut from the original crystal in such a manner that its faces are parallel to the B and C axes and perpendicular to the A axis, and is provided with electrodes on its faces, the condenser thus formed will have a capacity several thousand times as large as would be expected from a condenser of equal dimensions having glass or mica as a dielectric. This results from the fact that the dielectric constant of Rochelle Salts is very large, approximately 10,000. However, this value is not constant and may, under certain conditions, be as high as 100,000 or as low as 1,000.

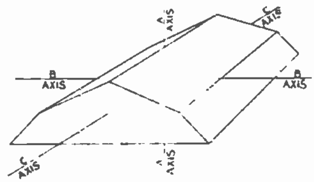


Fig. 30 A Rochelle Salts crystal showing the various axes.

The capacity of this condenser varies with temperature and saturation characteristics are exhibited which are similar to those found in iron. For example, when the voltage applied to this condenser exceeds a certain value (about 250 volts per inch of dielectric at ordinary temperatures) a further increase in voltage does not result in a corresponding increase of charge on the condenser. Resonance effects are present also, for if the condenser is excited with alternating current and the frequency is increased gradually, a point will finally be reached at which the capacity begins to increase rapidly with an increase in frequency. This is near the natural period or resonance point of the condenser. Beyond the resonance point, the reactance of the condenser suddenly changes from capacitive to inductive and the crystal behaves as an inductor instead of a condenser for a short frequency range.

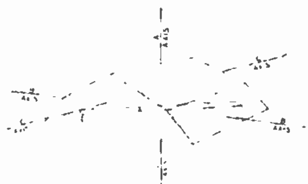


Fig. 31 Illustrating how the crystal plate is cut from the original crystal.

The most important phenomenon connected with the Rochelle Salts crystal is the piezo-electric effect. When a voltage of a given polarity is applied to the faces of the plate, a contraction in a direction parallel to the faces and at 45° to the B and C axes occurs. Simultaneously an expansion results in a direction perpendicular to the direction of the contraction and in the plane of the B and C axes. When the polarity of the voltage is reversed, the directions of expansion and contraction are reversed. When an alternating voltage is applied to the plate, the entire plate vibrates very noticeably.

For use in microphones, the plate is cut from the original Rochelle Salts crystal as shown in Fig. 31. Its faces are parallel to the plane formed by the B and C axes and its sides extend at an angle of 45° to the B and C axes. It is cut in this manner, because as previously mentioned the expansion and contraction of the crystal occur along a line drawn at an angle of 45° to the B and C axes. When a voltage is applied to the faces of this plate, it will expand and contract longitudinally, as the polarity of the voltage changes. It will also contract and expand laterally, but since the lateral dimension is small, it is ordinarily neglected.

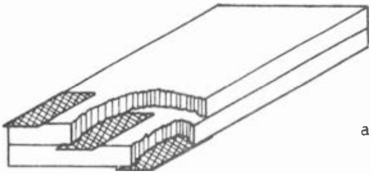


Fig.32 The construction of a bimorph element.

Crystal microphones themselves are made up of bimorph elements. A bimorph element consists of two Rochelle Salts plates cemented together as shown in Fig. 32. As may be seen from this figure, three electrodes are provided, one on each of the outer faces of the element and one between the two plates composing the element. It is found that if one terminal of a battery or voltage source is connected to the internal electrode and the two outside terminals are connected to the other terminal of the battery, the crystal can be caused, if the plates are cemented together in opposition, to bend. This results, because one of the plates tends to contract as

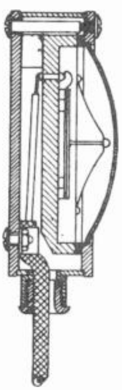


Fig.33 The diaphragm type of crystal microphone.

the other plate expands. When the polarity of the voltage source is reversed, the plate which before had expanded will now contract and vice versa, resulting in a bending of the crystal plate in the opposite direction. Furthermore, if the unit is bent by applying to it a mechanical force, an electromotive force will result, since the bending will compress one crystal and place the other in tension. Thus, it is possible to increase the amount of motion for a given potential difference, or to secure a larger potential difference for a given applied force.

Perhaps the most important advantage gained by this combination, however, is that the unit thus obtained is free from the effects of temperature on the output voltage and the saturation point is raised so much that within the possible working range, the crystal is not affected by saturation.

If a bimorph element is supported at two points in the exact center of two opposite edges and a sound wave is impressed upon the surfaces, a double curvature will result, causing an e.m.f. to be developed, which is in direct proportion to the frequency rate of the vibration.

Crystal microphones are divided into two general types; those employing a diaphragm and those in which a diaphragm is not used. A diagram illustrating the construction of the diaphragm type is shown in Fig. 33. It has a conical duraluminum diaphragm which actuates the bimorph element. The greatest disadvantage of this type of microphone is the fact that it has an inherent tendency to resonate at some point in the musical frequency spectrum. This is due to a pressure doubling effect, caused by reflections which in turn are caused by the arrangement of the crystals of the bimorph element.

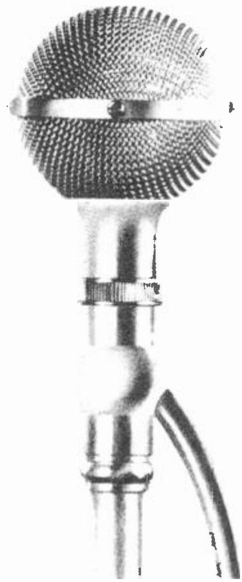


Fig.34 A photograph of the cell type of crystal microphone.

The foregoing disadvantages are eliminated by the use of sound cells. A sound cell is an assembly of two bimorph elements sensitive to bending and held together in a bakelite frame. The assembly is so made that the finished unit is in itself a complete, though small, microphone. The two bimorph elements are supported in the case at two points. Enough clearance is provided between the elements so that the plates are easily distorted by variations in pressure. Silver electrodes from each element are brought out at the point of contact with the frame. The entire unit is impregnated in wax to provide an airtight and moisture-proof assembly. This results in a small, flat, hollow airtight box, the two major surfaces of which generate voltages corresponding directly to the acoustical pressure. The two bimorph elements are so arranged that the voltages generated by each are in phase; that is, the voltage of one adds to the voltage of the other. This is true when the disturbance is due to a sound wave, but the two voltages are out of phase and buck when the pressure is occasioned by mechanical shock or vibration. For this reason, such microphones can be handled while in use without requiring elaborate methods of suspension and are remarkably quiet in a wind.

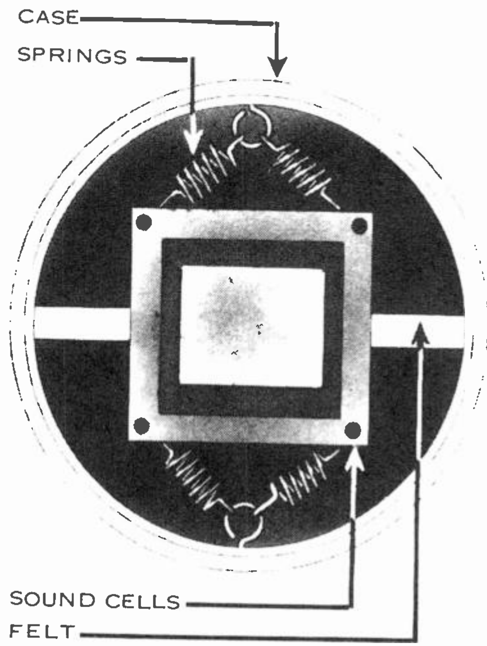


Fig.35 The construction of the microphone illustrated in Fig. 34.

In one standard size the dimensions of the bimorph element are $\frac{7}{16}$ inch square by .02 inch thick. The frequency response curve is flat to 6,000 cycles with a slightly rising characteristic beyond this point. One advantage of this rising characteristic is that it compensates for a loss in the high frequencies usually found in associated equipment with which the microphone is used and results in a flat composite frequency curve from 5 to 10,000 cycles. To produce this flat frequency response curve requires that the resonant frequency of the crystal be slightly above 10,000 cycles.

The output voltage generated by a single cell is approximately .125 millivolt per plate. The impedance is highly capacitively reactive and has, in addition a small effective resistance so that its impedance value near 10,000 cycles is approximately 5,000 ohms. Ordinarily, the sound cells are connected in parallel in order to reduce the output impedance. This is necessary so that reasonable long cables can be connected between the microphone and the vacuum tube amplifier. One type of sound cell microphone is illustrated in Fig. 34. A sectional view of this microphone is shown in Fig. 35. It shows one of the two sound cells looking down from above, and also the supporting springs, side lugs and felt. The microphone is, of course, practically non-directional. On the average, the output level of a sound cell microphone is approximately -85 db.

Since the output impedance of the crystal microphone is rather large, it may be connected directly to the grid circuit of its amplifier without the use of a matching transformer. One type of amplifier often used with a crystal microphone is shown in Fig. 36. R1 is the input grid leak resistance which allows the application of

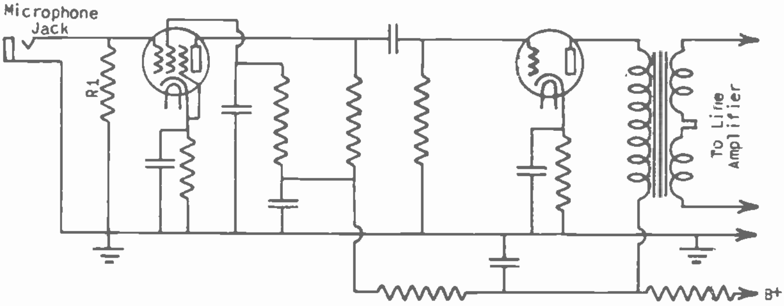
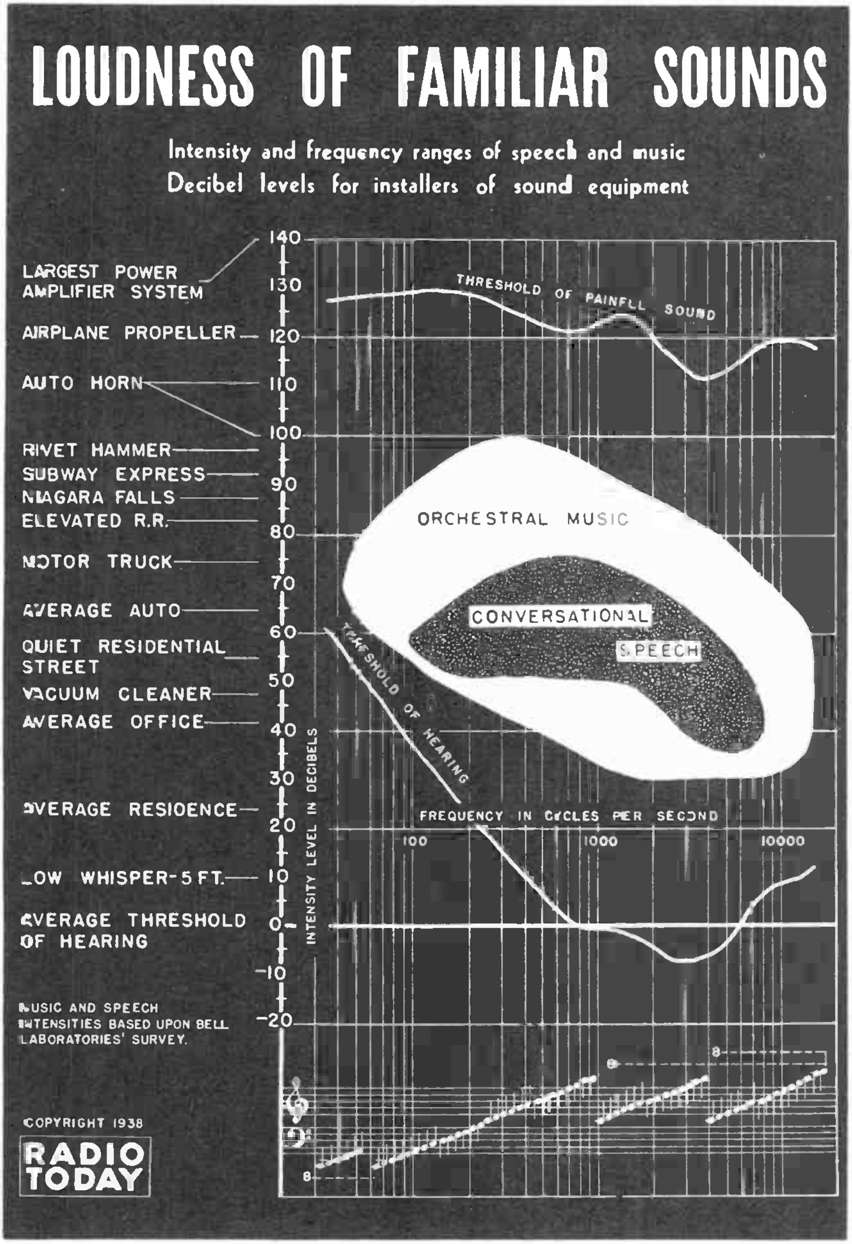


Fig.36 A pre-amplifier circuit for use with a crystal microphone.

the grid bias to the tube and prevents blocking, owing to the condenser effect of the microphone element. It should be at least 5 megohms to insure a high input impedance at all frequencies and thus make the frequency response more nearly flat.

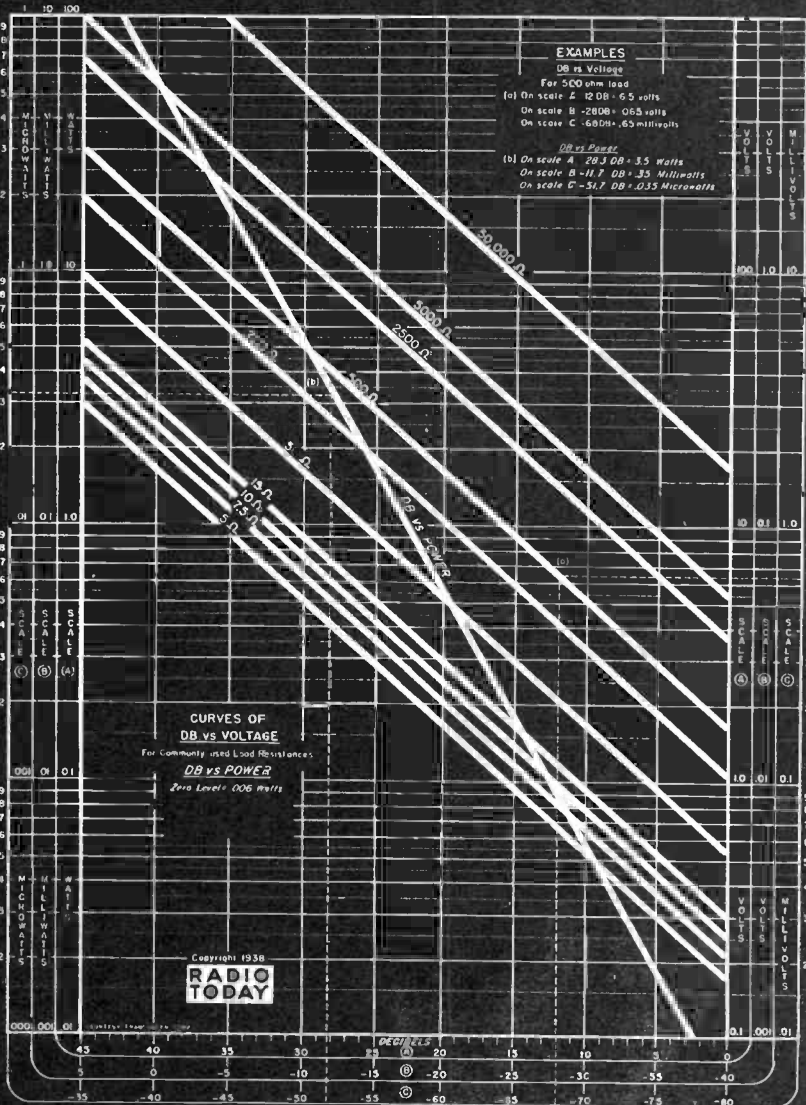
Notes

(These extra pages are provided for your use in taking special notes)


LOUDNESS OF FAMILIAR SOUNDS
Intensity and frequency ranges of speech and music
Decibel levels for installers of sound equipment
LARGEST POWER AMPLIFIER SYSTEM
AIRPLANE PROPELLER
AUTO HORN
RIVET HAMMER
SUBWAY EXPRESS
NIAGARA FALLS
ELEVATED R.R.
MOTOR TRUCK
AVERAGE AUTO
QUIET RESIDENTIAL STREET
VACUUM CLEANER
AVERAGE OFFICE
AVERAGE RESIDENCE
LOW WHISPER-5 FT.
AVERAGE THRESHOLD OF HEARING
MUSIC AND SPEECH INTENSITIES BASED UPON BELL LABORATORIES' SURVEY.
COPYRIGHT 1938
RADIO TODAY
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
INTENSITY LEVEL IN DECIBELS
THRESHOLD OF PAINFUL SOUND
ORCHESTRAL MUSIC
CONVERSATIONAL SPEECH
THRESHOLD OF HEARING
FREQUENCY IN CYCLES PER SECOND
100
1000
10000
8
8
8

DECIBELS EXPRESSED IN VOLTS & WATTS

For matching microphones, amplifiers, and speakers



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MIDLAND RADIO AND TELEVISION SCHOOLS INC.

POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 4

PADS AND LINE EQUALIZERS

LESSON NO. 3

LUIGI GALVANI

.....and an accidental discovery.

Galvani, from whose name we get many common terms, was an Italian physiologist, born in Bologne, Italy, September 9, 1737.

Having gained considerable attention from his research and experiments on birds and frogs, he arrived at a conclusion that animals possessed electricity.

The manner in which this theory was originated is rather interesting. Galvani had hung a dead frog to an iron fence by means of copper hooks. When the frog's leg came in contact with the iron fence, he noticed the twitching and quivering of the animal's muscles. While he first believed that the animal might still be alive, he later erroneously concluded that the frog had electricity in it. Later on he advanced his famous theory that all animals possessed electricity, and today there are still many people who believe this to be a fact.

Later on, Alessandro Volta, who gained fame as a philosopher, physicist and pioneer in electricity, who invented the voltaic pile, proved that the frog acted as a conductor, and that the reason its leg twitched when it came in contact with the iron fence was because a small electrical current had been created by the contact of two dissimilar metals through the frog's body. Today, instruments that are used to measure small electrical currents are operated on the same theory and are called 'galvanometers'.

While Galvani himself never made any other experiments in the field of electricity, the accidental result of his work in anatomy perpetuated his name in the field of electricity.

In the past, many new developments have been produced through accidental discoveries. However, such fortunate accidents would not have happened had not scientists devoted their time and energy so tirelessly to the solving of unknown problems and the seeking of new things to better our lives. The discoveries of scientists have opened the remarkable field of radio to you. Take full advantage of your opportunities by training yourself for profitable participation in this new field.

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Lesson Three

PADS & LINE EQUALIZERS

"The fidelity of the audio frequency circuits in a radio broadcasting station is becoming increasingly important. The modern public demands high quality reception. To satisfy this demand, broadcast engineers incorporate numerous devices for the sole purpose of maintaining high quality transmission.

"The components of an A.F. system as described in this lesson are essential in the design of high fidelity apparatus. A knowledge of these components, their design, construction, and operation will be found of great value in the broadcast field."

1. **ATTENUATING DEVICES.** We are all familiar with the purpose and function of a volume control on a radio receiving set. In the audio frequency circuits at a broadcast station and in sound recording work, it is likewise necessary to provide a means of controlling the level of the A.F. energy. These controls are known to the engineer as "attenuators", "pads", "mixers", or "faders", according to their use in the A.F. circuits. An attenuator or a pad may be any fixed or variable resistance combination used for the purpose of attenuating (reducing) the A.F. energy level. Controls known as mixers are employed to "mix" or combine the outputs of two or more A.F. energy sources (phonograph pickups, microphones, etc.) into a common amplifying channel. Faders consist of variable controls used to effect a smooth change from one A.F. circuit to another. Examples of each of these types of controls will be given in later paragraphs of this lesson.

2. **FIXED PADS.** A fixed pad is a resistive network placed in an audio frequency circuit for the purpose of introducing a definite and constant loss in the level of the A.F. energy passing through the circuit. It is considered better practice to reduce the A.F. signal strength in this manner instead of decreasing the efficiency of a vacuum tube or an amplifier because both of the latter methods are apt to introduce frequency and harmonic distortion. A pure resistance network can be designed so that no distortion will be in-

troduced and it makes possible a precise and noiseless control on the level of the A.F. energy. As well as attenuating the signal level, a fixed (or variable) pad must also satisfy the requirements of impedance matching. Having previously learned the importance of impedance matching in A.F. circuits, we cannot neglect the fact that the proper impedance relations must be maintained when a pad is inserted.

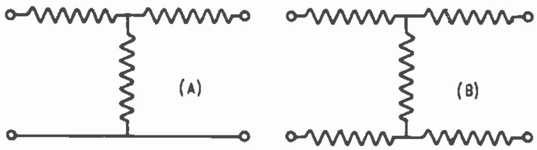


Fig. 1 (A) T type attenuating pad. (B) H type attenuating pad.

The principal types of pad networks are given the names T and H because of their similarity to these letters when shown on circuit diagrams. A and B in Fig. 1 illustrate the T and H pads respectively. To demonstrate the use of a fixed pad in an A.F. amplifying system, let us refer to Fig. 2. Here the output of the microphone amplifier and the output of a phonograph pickup are to be fed selectively into a second A.F. amplifier. The db level at the output of the first amplifier is -30 and at the output of the pickup, the level is -15 db. Let us suppose that the changeover switch is in the "up" position so as to connect the microphone

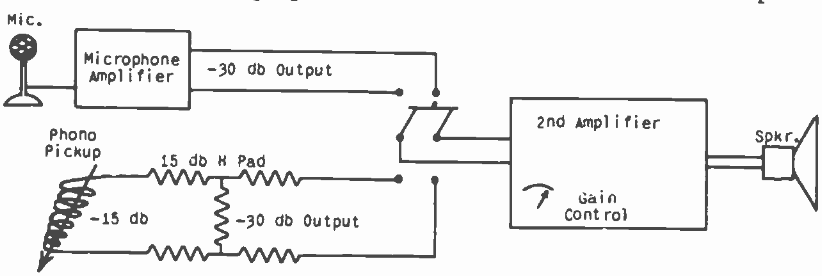


Fig. 2 Simplified circuit showing the use of a fixed pad.

through the second amplifier. The gain control on the second amplifier would then be adjusted to produce the desired sound energy level from the speaker. When a change of microphone to pickup is desired, the switch is thrown to the down position. If the 15 db pad were not in the pickup circuit, the level of the input to the second amplifier would be 15 db higher, which is sufficient to seriously overload the first amplifying tubes, the loud speaker, or both. Overloading at the output of the amplifier could be avoided by reducing the gain control on the amplifier; however, this may not correct the distortion produced by excessive input to the first amplifying tubes. Inserting the H pad in the phonograph pickup circuit. greatly simplifies the whole system. With a 15 db loss occuring in the pad, the -15 db output of the pickup is reduced to -30, the same as the output of the microphone amplifier. The pad does not introduce any form of distortion if it is properly designed. When the changeover from amplifier to pickup is effected, the gain control on the second amplifier can remain in the same position, the first amplifying tubes will not be overloaded, and the sound level from the speaker will be the same as before.

A few of the common uses for fixed pads include: To match the audio levels from different types of microphones, to reduce the db level at the terminating end of a remote broadcast telephone line, to decrease the A.F. output from phonograph pickups, to match impedances, and to isolate circuits from line impedance changes. The T and H pads as shown in Fig. 1 will produce the desired db loss and, at the same time, maintain the correct impedance relations between the input and output circuits. A T pad does not maintain a correctly "balanced" condition on the two sides of the line because all of the series resistance is inserted on one side. This may or may not be important in specific cases, but it is the main reason for using H pads more frequently in broadcast circuits. With equal series resistance in both sides of the A.F. line, a balance to ground is obtained with an H pad which tends to reduce greatly the extraneous pick-up and cross-talk noises in the line.

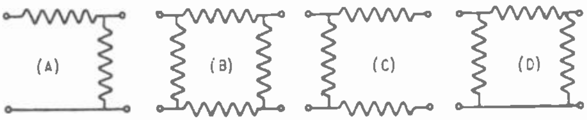


Fig.3 (A) L pad. (B) O pad. (C) U pad. (D) Pi pad.

All types of fixed pads may be classified as balanced or unbalanced, and symmetrical or unsymmetrical. A balanced pad is one having equal resistance values on both sides of the circuit; the H pad is an example, but the T pad is not. A symmetrical pad is one that is symmetrical with respect to the source and load sides; that is, from the center of the pad, the same number of ohms are seen looking into either the source or load if the source and load impedances are equal. When input and output impedances are equal, all T and H pads are symmetrical. An L pad, constructed as shown at A in Fig. 3, is non-symmetrical and unbalanced. An O, U, and π (pi) pad are illustrated at B, C, and D, respectively, in Fig. 3. Between equal impedances, the O pad is balanced and symmetrical, the U pad is non-symmetrical and balanced, while the π pad is symmetrical but unbalanced. A in Fig. 4 shows an H pad which is balanced not only with regards to the series elements, but also in the shunt branch. Grounding the shunt element in the center completely balances the symmetrical pad in all directions.

Perhaps the need for all these different types of pads is not apparent to the student. Presently, we shall inspect several tables which specify the resistance values to use for a given amount of attenuation between two impedances. The tables will reveal that the resistors attain absurd values for high and low attenuation.

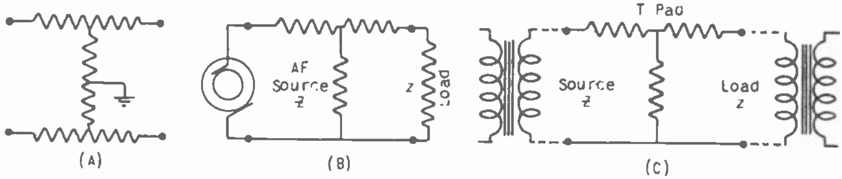


Fig.4 (A) H pad balanced to ground. (B) T pad indicating input impedance (Ƶ) and output impedance (z). (C) Showing T pad connected between source (Ƶ) and load (z) impedances.

Shifting from one type of pad to another will often bring the resistors into reasonable and readily obtainable values. For high attenuation, the difficulty can often be solved by placing two or more pads in series. The total attenuation will then be the sum of the losses in each individual pad.

3. IMPEDANCE MATCHING WITH RESISTANCE PADS. It is very important that the input impedance of a pad match the output impedance of the source of A.F. energy. Also, the output impedance should match the impedance of the load into which it is delivering its attenuated output. A fixed pad of the T, H, π, and O type can be made to match the input and output impedances by using the proper resistance values, but non-symmetrical pads, such as the L and U cannot be made to do so. For this reason, the use of L and U pads is confined to those types of A.F. circuits where a mis-matched condition on one side or the other is permissible. For instance, an L or U pad may be used when working as a voltage divider or volume control into the grid of an amplifier tube, or when working from an infinitely high impedance source which does not supply A.F. power. In short, L and U pads are used mainly as voltage dividers (fixed or variable) and not as power level attenuators.

The input impedance of a pad is defined as the impedance looking into the attenuator from the source side (with the source generator disconnected) when the load on the output side is connected. We shall use Ƶ as the symbol to designate the source impedance and "z" to designate the load impedance. In diagram B, Fig. 4, the input impedance of the T pad would be the number of ohms presented by the resistive network to Ƶ when z is connected. The input impedance represents the actual load on an A.F. source of power (generator) at Ƶ. The source of A.F. power ordinarily will be the secondary of a transformer and the load impedance will be the primary of an input transformer as shown at C in Fig. 4.

The output impedance of a pad is the impedance which is seen upon looking into the attenuator from the load side (with the load disconnected) when the source impedance is connected. In Fig. 4, this would be the impedance looking from z to Ƶ, with Ƶ connected and z disconnected. The output impedance of the pad may be considered equivalent to the internal impedance of the A.F. source that is delivering audio power into the load impedance z. For maximum power transfer, the pad's output impedance should correctly match the impedance of z.

The attenuation that is produced by a pad may be defined as the "insertion loss"; that is, the audio output level actually obtained across z compared with the level that would be obtained with the pad removed. This attenuation may be expressed in volts, dbs, or watts; however, the db is the unit that is consistently used.

4. DETERMINING THE RESISTOR VALUES FOR PADS. The attenuation produced by a pad depends upon the relative sizes of the series and shunt resistive elements, and upon the source and load impedances in relation to the input and output impedances of the pad. Assuming that resistance values will be selected to properly match the source and load impedances, the attenuation then depends only upon the proportionate sizes of the resistors. Resistor values can be chosen which will produce the desired amount of attenuation (in dbs) between the input and output impedance for any type of pad. Of course, there are limitations on the extent of the attenuation, the upper limit is reached when the resistors attain impractical values (generally extremely small or negative values) and the lower limit of attenuation is dependent upon the ratio of the source and load impedances which the pad must match. For equal input and output impedances, practical resistor values can ordinarily be obtained (or made) to produce attenuation between 1 and 70 db. This range is narrowed when matching between unequal impedances.

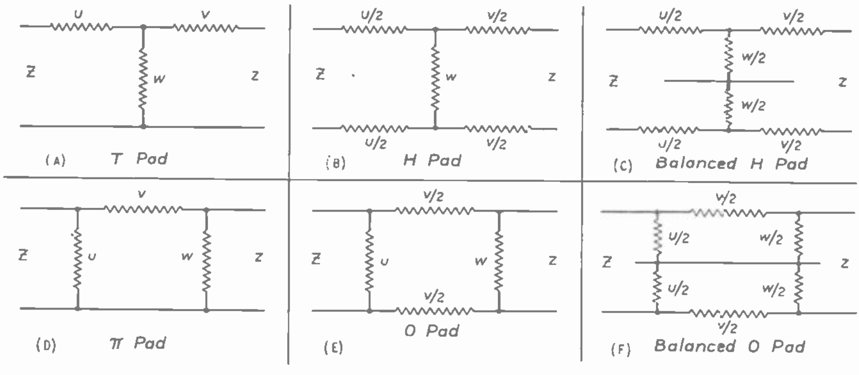


Fig.5 Pad circuits labeled to correspond with the tables on the following pages.

It is possible to calculate the resistor values needed to satisfy the attenuation and impedance requirements by using formulas which have been devised for the purpose. Most of these formulas require the use of logarithms, so we shall not expect the student to become proficient in the use of the formulas unless he has had previous training in that branch of mathematics. In broadcast station practice, the input and output impedances of the various pieces of equipment are fairly well standardized. The common values are 50, 200, 250, and 500 ohms. In order that the student will be in a position to design a pad to work between these impedance values, we are supplying several tables on the following pages. It will be found that virtually all of the problems which arise during broadcast station operation can be solved using these tables. The resistor values are given in ohms. Fig. 5 shows the labeled drawings to which the values specified in the tables refer. The left column in the tables give values which apply to A, B, and C of Fig. 5, while the values in the right columns refer to pads such as D, E and F of Fig. 5.

For those students acquainted with the use of logarithms, formulas are given starting on Page 35 for the solution of problems that cannot be read directly from the tables. Due to their infrequent use, L type fixed pads are not included in the tables; however, formulas on Page 35 enables the calculation of these types of pads. Let us work a few examples to illustrate the use of the foregoing tables.

Example 1: Design a T pad to produce a 15 db loss working between source and load impedances of 500 ohms each.

Solution: Table 1 gives the resistance values for Ƶ (source impedance) of 500 ohms and z (load impedance) of 500 ohms. The left side of table 1 should be used for a T pad. Come down the left column headed "loss - db" to 15, then go across to the next three columns headed "u", "w", and "v". Now, referring to A in Fig. 5, we see that the resistance value given for "u" is the size for the left series arm of the pad; "w" is the value of the shunt resistor; and "v" is the value of the right series arm. In the table, we find these values to be 356 ohms, 184 ohms, and 356 ohms respectively. A T pad using these values will properly match 500 ohm input and output impedances and will produce a db loss of 15. If the more practical values of 350, 185, and 350 ohms are used, the results will be sufficiently close for most work.

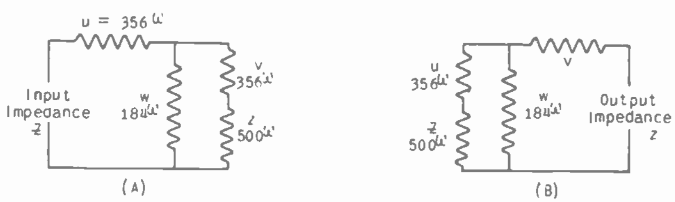


Fig.6 (A) Drawing of T network to illustrate load on Ƶ. (B) Drawing of T network to illustrate source impedance for z.

Suppose we take this first example and show how the resistor values used will supply the correct impedance load on the A.F. signal source at Ƶ. A in Fig. 6 shows the same resistor network, but drawn in a slightly different manner. To find the total resistance

Z = 500Ω z = 500Ω

LOSS						
db.	u	w	v	u	v	w
1	28.9	4334.	28.9	8690.	57.5	8690.
2	57.3	2152.	57.3	4360.	116.	4360.
3	85.5	1419.	85.5	2920.	176.	2920.
4	113.	1048.	113.	2210.	238.	2210.
5	140.	822.	140.	1785.	304.	1785.
6	166.	669.	166.	1500.	372.	1500.
7	191.	558.	191.	1310.	448.	1310.
8	215.	473.	215.	1160.	528.	1160.
9	238.	406.	238.	1050.	613.	1050.
10	260.	351.	260.	962.	713.	962.
11	280.	306.	280.	890.	815.	890.
12	300.	268.	300.	835.	930.	835.
13	317.	236.	317.	785.	1060.	785.
14	333.	208.	333.	749.	1220.	749.
15	356.	184.	356.	715.	1360.	715.
16	363.	163.	363.	688.	1538.	688.
17	376.	144.	376.	664.	1733.	664.
18	388.	128.	388.	644.	1952.	644.
19	399.	114.	399.	626.	2200.	626.
20	408.	101.	408.	612.	2475.	612.
22	426.	80.	426.	586.	3125.	586.
24	443.	63.	443.	567.	3940.	567.
26	450.	50.	450.	552.	4980.	552.
28	462.	40.	462.	540.	6280.	540.
30	469.	32.	469.	530.	7900.	530.
32	475.	25.	475.	525.	9940.	525.
34	480.	20.	480.	520.	12,500.	520.
36	484.	16.	484.	515.	15,780.	515.
38	487.	13.	487.	512.5	19,850.	512.5
40	490.	10.	490.	510.0	25,000.	510.0
42	492.	8.	492.	508.0	31,400.	508.0
44	493.	6.3	493.	506.0	39,800.	506.0
46	495.	5.0	495.	505.0	49,800.	505.0
48	496.	3.9	496.	504.0	63,100.	504.0
50	497.	3.1	497.	503.0	79,200.	503.0
55	498.	1.7	498.	502.0	142,000.	502.0
60	498.	1.0	498.	501.0	250,000.	501.0
65	499.	0.56	499.			
70	499.	0.31	499.			

1

Z = 500Ω z = 250Ω

LOSS						
db.	u	w	v	u	v	w
8	353.	335.	9.0	760.	374.	373.
9	357.	288.	34.0	697.	436.	350.
10	364.	248.	58.	688.	505.	345.
11	369.	217.	76.	674.	578.	338.
12	377.	190.	94.	660.	660.	331.
13	386.	167.	109.	639.	750.	320.
14	394.	147.	124.	632.	852.	317.
15	403.	130.	136.	626.	964.	311.
16	411.	115.	148.	608.	1,090.	305.
17	418.	102.	158.	597.	1,228.	299.
18	426.	90.	168.	587.	1,384.	294.
19	433.	80.	176.	578.	1,559.	289.
20	438.	72.	183.	570.	1,752.	285.
22	449.	57.	196.	562.	2,217.	278.
24	456.	45.	206.	545.	2,790.	273.
26	467.	36.	215.	535.	3,520.	268.
28	474.	28.	222.	526.	4,420.	264.
30	479.6	22.4	227.6	522.	5,580.	261.
32	482.2	17.8	232.2	518.	7,040.	259.
34	486.9	14.1	235.9	514.	8,850.	257.
36	488.8	11.2	238.8	512.	11,170.	256.
38	491.1	8.9	241.1	509.	13,140.	254.
40	492.9	7.1	242.9	507.	17,700.	254.[illegible]
42	494.4	5.6	244.4	506.	22,280.	253.
44	495.5	4.5	245.5	505.	28,080.	252.5
46	496.5	3.5	246.5	504.	35,300.	252.
48	497.2	2.8	247.2	502.5	44,400.	251.5
50	497.8	2.2	247.8	502.	56,000.	251.
55	498.7	1.3	248.7	501.5	99,500.	251.
60	499.3	0.7	249.3	501.	177,000.	250.5

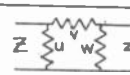
2

Z = 500Ω z = 50Ω

LOSS						
db.	u	w	v	u	v	w
16	474.	51.	0.5	930.	486.	52.7
17	474.5	45.5	6.5	850.	548.	52.6
18	475.8	40.2	11.4	789.	617.	52.5
19	476.	35.	15.2	750.	737.	52.4
20	478.	32.	19.	714.	782.	52.3
22	481.	25.	25.6	664.	990.	52.
24	484.	20.	30.4	620.	1,247.	51.7
26	487.	16.	34.3	591.	1,573.	51.4
28	489.5	12.5	37.7	570.	1,983.	51.1
30	491.	10.	40.1	554.	2,495.	50.9
32	492.	8.	42.	543.	3,140.	50.7
34	493.7	6.3	43.7	533.	3,950.	50.6
36	495.	5.	45.	526.	4,980.	50.4
38	496.	4.	46.	520.	6,270.	50.35
40	496.8	3.2	46.8	517.	7,890.	50.3
42	497.5	2.5	47.5	513.	9,920.	50.25
44	498.	2.	48.	510.	12,530.	50.2
46	498.4	1.6	48.4	508.	15,780.	50.2
48	498.7	1.3	48.7	506.	19,840.	50.15
50	499.	1.	49.	505.	25,000.	50.1
55	499.4	0.6	49.4	503.	44,400.	50.1
60	499.7	0.3	49.7	502.	78,000.	50.05

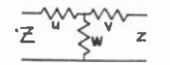
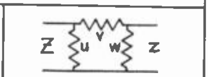
3

Z = 500Ω z = 200Ω

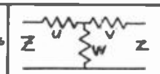
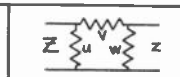
LOSS						
db.	u	w	v	u	v	w
8				783.	334.	257.
9	388.	266.	2.0	765.	389.	256.
10	390.	222.	22.0	742.	451.	255.
11	392.	194.	41.0	720.	516.	253.
12	397.	170.	57.0	698.	589.	250.
13	404.	149.	72.	678.	670.	247.
14	411.	131.	85.	662.	760.	244.
15	417.	116.	97.	646.	860.	240.
16	423.	103.	107.	629.	973.	236.
17	431.	91.	117.	615.	1.096.	233.
18	436.	81.	126.	602.	1.236.	230.
19	441.	72.	133.	591.	1.390.	226.
20	446.	64.	140.	581.	1 566.	224.
22	455.	51.	151.	565.	1,978.	219.
24	464.	40.	162.	550.	2.470.	216.
26	471.	32.	169.	541.	3.145.	213.
28	477.	25.	175.	531.	3.960.	210.
30	479.	20.	180.	524.	4.980.	208.
32	484.	16.	184.	520.	6.280.	206.5
34	487.4	12.6	187.4	517.	7.910.	205.
36	490.	10.	190.	512.	9,960.	204.
38	492.	8.	192.	510.	12,550.	203.
40	493.4	6.6	193.4	508.	16.730.	202.5
42	495.	5.	195.	506.	19,900.	202.
44	496.	4.	196.	505.	25,500.	201.5
46	496.8	3.2	196.8	504.	31,600.	201.5
48	497.5	2.5	197.5	502.5	39,650.	201.
50	498.	2.	198.	502.	50,000.	200.8
55	498.9	1.1	198.9	501.5	88,800.	200.6
60	499.4	0.6	199.4	501.	158,000.	200.5
65	499.7	0.3	199.7			
70	499.8	0.2	199.8			

4

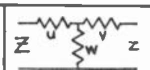
Courtesy "Communications"

LOSS	Z = 250Ω 			z = 250Ω 		
db.	u	w	v	u	v	w
1	14.4	2165.	14.4	4,350.	28.8	4,350.
2	28.6	1076.	28.6	2,180.	58.0	2,180.
3	42.8	709.	42.8	1,461.	88.	1,461.
4	56.6	520.	56.6	1,104.	119.	1,104.
5	70.	411.	70.	892.	152.	892.
6	83.	334.	83.	750.	187.	750.
7	96.	279.	96.	653.	224.	653.
8	108.	236.	108.	581.	264.	581.
9	119.	206.	119.	526.	308.	526.
10	130.	175.	130.	481.	357.	481.
11	140.	153.	140.	446.	408.	446.
12	150.	134.	150.	418.	466.	418.
13	159.	116.	159.	394.	530.	394.
14	167.	104.	167.	374.	602.	374.
15	175.	92.	175.	358.	680.	358.
16	182.	81.	182.	344.	770.	344.
17	188.	72.	188.	332.	866.	332.
18	194.	64.	194.	322.	976.	322.
19	200.	57.	200.	313.	1,100.	313.
20	204.	50.5	204.	306.	1,238.	306.
22	213.	40.	213.	293.	1,564.	293.
24	220.	31.5	220.	284.	1,971.	284.
26	226.	25.	226.	276.	2,488.	276.
28	231.	20.	231.	271.	3,135.	271.
30	234.	16.	234.	266.	3,945.	266.
32	238.	12.	238.	263.	4,970.	263.
34	240.	10.	240.	260.	6,250.	260.
36	242.	8.	242.	258.	7,880.	258.
38	244.	6.	244.	256.	9,920.	256.
40	245.	5.	245.	255.	12,500.	255.
42	246.	4.	246.	254.	15,650.	254.
44	247.	3.	247.	253.	19,800.	253.
46	248.	2.5	248.	252.	24,950.	252.
48	248.	2.	248.	252.	31,200.	252.
50	248.	1.6	248.	251.	39,500.	251.
55	249.	0.9	249.	251.	70,300.	251.
60	250.	0.5	250.	250.	125,000.	250.
65	250.	0.28	250.	250.	222,000.	250.
70	250.	0.15	250.	250.	395,000.	250.

5

LOSS	Z = 250Ω 			z = 200Ω 		
db.	u	w	v	u	v	w
6	120.	298.	36.			
7	125.	249.	46.			
8	133.	211.	64.			
9	141.	181.	77.			
10	149.	157.	87.			
11	156.	137.	97.			
12	164.	120.	107.			
13	171.	105.	116.	297.	473.	292.
14	177.	93.	123.	294.	573.	281.
15	184.	82.	131.	291.	607.	272.
16	191.	72.	138.	288.	685.	263.
17	196.	64.	144.	285.	774.	255.
18	201.	57.	149.	281.	871.	249.
19	205.	51.	154.	278.	981.	242.
20	210.	45.	159.	276.	1,104.	238.
22	217.	36.	166.	271.	1,396.	230.
24	224.	28.	174.	267.	1,760.	224.
26	228.6	22.4	178.6	263.	2,220.	220.
28	233.	18.	183.	261.	2,800.	215.
30	236.	14.	186.	259.	3,520.	212.
32	238.7	11.3	188.7	257.	4,430.	209.
34	241.1	8.9	191.1	256.	5,675.	207.
36	242.9	7.1	192.9	254.5	7,035.	206.
38	244.4	5.6	194.4	253.5	8,850.	204.5
40	245.5	4.5	195.5	253.	11,140.	203.5
42	246.5	3.5	196.5	252.	14,030.	203.
44	247.2	2.8	197.2	251.5	17,700.	202.
46	247.8	2.2	197.8	251.	22,250.	201.7
48	248.2	1.8	198.2	251.	28,000.	201.5
50	248.6	1.4	198.6	251.	35,250.	201.2
55	249.2	0.8	199.2	250.5	62,700.	201.
60	249.6	0.4	199.6	250.5	111,500.	200.4

6

LOSS	Z = 250Ω 			z = 50Ω 		
db.	u	w	v	u	v	w
13	223.	53.	2.0	433.	238.	55.7
14	224.5	46.5	7.5	404.	269.	55.5
15	225.	41.	12.	383.	305.	55.4
16	226.6	36.4	16.1	363.	344.	55.1
17	227.7	32.3	19.7	348.	391.	54.7
18	229.4	28.6	23.	336.	437.	54.4
19	230.6	26.4	26.9	324.	493.	54.2
20	232.4	22.6	28.4	315.	555.	53.8
22	235.	18.	33.6	300.	701.	53.1
24	238.	14.	37.4	208.	884.	52.6
26	240.7	11.3	39.	288.	1,130.	52.1
28	242.	9.	40.8	274.	1,405.	51.7
30	242.9	7.1	43.1	266.	1,768.	51.4
32	244.4	5.6	44.5	265.	2,226.	51.1
34	245.5	4.5	45.5	261.	2,820.	50.8
36	246.4	3.6	46.4	259.	3,530.	50.7
38	247.2	2.8	47.2	258.	4,440.	50.6
40	247.8	2.2	47.8	256.	5,590.	50.4
42	248.2	1.8	48.2	255.	7,050.	50.3
44	248.6	1.4	48.6	254.	8,870.	50.25
46	248.9	1.1	48.9	253.	11,170.	50.25
48	249.1	0.9	49.1	252.6	14,050.	50.2
50	249.3	0.7	49.3	252.	17,700.	50.15
55	249.6	0.4	49.6	251.	31,150.	50.1
60	249.8	0.2	49.8	250.5	56,000.	50.

7

Courtesy "Communications"

LOSS	Z = 200Ω 			z = 200Ω 		
db.	u	w	v	u	v	w
1	11.6	1735.	11.6	3460.	23.	3460.
2	22.9	861.	22.9	1745.	46.5	1745.
3	34.2	567.	34.2	1170.	70.5	1170.
4	45.3	419.	45.3	883.	95.4	883.
5	56.	329.	56.	714.	122.	714.
6	66.5	268.	66.5	602.	149.	602.
7	76.5	223.	76.5	523.	179.	523.
8	86.	189.	86.	465.	211.	465.
9	95.	162.	95.	420.	246.	420.
10	104.	140.	104.	385.	286.	385.
11	112.	122.	112.	357.	327.	357.
12	120.	107.	120.	334.	373.	334.
13	127.	94.	127.	315.	424.	315.
14	133.	83.	133.	300.	481.	300.
15	140.	73.	140.	287.	546.	287.
16	145.	65.	145.	275.	615.	275.
17	150.	58.	150.	266.	694.	266.
18	155.	51.	155.	258.	782.	258.
19	160.	45.5	160.	251.	880.	251.
20	164.	40.5	164.	244.	990.	244.
22	171.	32.	171.	234.	1,251.	234.
24	176.	25.	176.	227.	1,579.	227.
26	181.	20.	181.	221.	1,990.	221.
28	185.	16.	185.	216.	2,508.	216.
30	188.	12.5	188.	213.	3,159.	213.
32	190.	10.	190.	210.	3,979.	210.
34	192.	8.	192.	208.	5,010.	208.
36	194.	6.3	194.	206.	6,308.	206.
38	195.	5.	195.	205.	7,942.	205.
40	196.	4.	196.	204.	9,999.	204.
42	197.	3.2	197.	203.	12,588.	203.
44	197.	2.5	197.	202.	15,849.	202.
46	198.	2.	198.	202.	19,953.	202.
48	198.	1.6	198.	201.	25,119.	201.
50	198.	1.3	198.	200.	31,623.	200.
55	199.	0.7	199.	200.	56,234.	200.
60	200.	0.4	200.	200.	100,000.	200.
65	200.	0.22	200.	200.	177,830.	200.
70	200.	0.13	200.	200.	316,230.	200.

8

LOSS	Z = 50Ω 			z = 50Ω 		
db.	u	w	v	u	v	w
1	2.9	433.	2.9	869.	5.2	869.
2	5.7	215.	5.7	436.	12.	436.
3	8.6	142.	8.6	292.	18.	292.
4	11.3	104.	11.3	221.	24.	221.
5	14.	82.	14.	179.	30.	179.
6	17.	67.	17.	150.	37.	150.
7	19.	56.	19.	131.	45.	131.
8	22.	47.	22.	116.	53.	116.
9	24.	41.	24.	105.	61.	105.
10	26.	35.	26.	96.	71.	96.
11	28.	31.	28.	89.	82.	89.
12	30.	27.	30.	84.	93.	84.
13	32.	24.	32.	79.	106.	79.
14	33.	21.	33.	75.	122.	75.
15	36.	18.	36.	72.	136.	72.
16	36.	16.	36.	69.	154.	69.
17	38.	14.	38.	66.	173.	66.
18	39.	13.	39.	64.	195.	64.
19	40.	11.	40.	63.	220.	63.
20	41.	10.	41.	61.	248.	61.
22	43.	8.	43.	59.	313.	59.
24	44.	6.3	44.	57.	394.	57.
26	45.	5.	45.	55.	498.	55.
28	46.	4.	46.	54.	628.	54.
30	47.	3.2	47.	53.	790.	53.
32	48.	2.5	48.	53.	994.	53.
34	48.	2.	48.	52.	1,250.	52.
36	48.	1.6	48.	52.	1,578.	52.
38	49.	1.3	49.	51.	1,985.	51.
40	49.	1.	49.	51.	2,500.	51.
42	49.2	0.8	49.2	50.8	3,140.	50.8
44	49.3	0.63	49.3	50.6	3,980.	50.6
46	49.5	0.5	49.5	50.5	4,980.	50.5
48	49.6	0.39	49.6	50.4	6,310.	50.4
50	49.7	0.31	49.7	50.3	7,920.	50.3
55				50.2	14,200.	50.2
60				50.1	25,000.	50.1

9

LOSS	Z = 200Ω 			z = 50Ω 		
db.	u	w	v	u	v	w
12	173.4	53.6	4.1			
13	174.	47.	8.3	316.	222.	59.3
14	174.5	41.5	13.5	300.	240.	57.1
15	176.3	36.7	16.6	286.	272.	56.7
16	177.5	32.5	20.	276.	308.	56.3
17	179.2	28.8	23.2	266.	347.	55.7
18	180.4	25.6	26.	258.	391.	55.3
19	182.3	22.7	28.6	250.	440.	54.8
20	183.8	20.2	30.8	244.	495.	54.4
22	186.	16.	33.4	234.	628.	53.6
24	189.3	12.7	37.7	228.	790.	53.2
26	191.	10.	39.7	222.	995.	52.4
28	193.	8.	42.2	216.	1,254.	51.9
30	193.7	6.3	43.8	213.	1,580.	51.6
32	195.	5.	45.	210.	1,990.	51.2
34	196.	4.	46.	208.	2,560.	50.9
36	196.8	3.2	46.8	207.	3,150.	50.8
38	197.5	2.5	47.5	205.	3,970.	50.7
40	198.	2.	48.	204.	4,990.	50.4
42	198.4	1.6	48.4	203.	6,295.	50.3
44	198.7	1.3	46.7	202.4	7,930.	50.2
46	199.	1.	49.	202.	9,960.	50.2
48	199.2	0.8	49.2	201.6	12,520.	50.2
50	199.4	0.6	49.4	201.4	15,820.	50.1
55	199.6	0.4	49.6	200.8	28,100.	50.1
60	199.8	0.2	49.8	200.2	50,000.	50.1

10

Courtesy "Communications"

of the combination, first add v and z to obtain 856 ohms in the right parallel branch, then divide the product of 856 and 184 (157,504) by the sum of 856 and 184 (1040). This gives 151 ohms as the resistance of the parallel circuit. Now add the 151 ohms to the 356 ohm series resistor "u" to obtain a total resistance for the circuit of 507 ohms. This is sufficiently close to the desired 500 ohms.

Now, if we turn the circuit around as at B in Fig. 6, the output impedance of the T pad may be calculated. Since z is the 500 ohm load for the A.F. energy source, the pad and source impedance Z should look like 500 ohms from z. Exactly the same values appear in this direction as when looking from Z, so the source impedance for z is 500 ohms.

Example 2: What resistor values should be used for an H pad working between a source impedance of 500 ohms and a load impedance of 250 ohms to produce a db loss of 30?

Solution: Table 2 gives the values for working between 500 and 250 ohms, and the left side of the table is used for an H pad. Come down the db column to 30, then across to obtain the values for u, w, and v. These are found to be 479.6, 22.4 and 227.6, respectively. Now, referring to B of Fig. 5, the value for each of the two series arms on the left side is found by dividing u by 2; this gives 239.8 for each of them. Likewise, the value for each of the two series arms on the right side is equal to v/2 or 113.8 ohms each. For the H pad shown at B, (unbalanced to ground) the value for w will be 22.4 ohms, but if it is desired to completely balance the pad in all directions, 11.2 ohms should be placed on either side of center as shown at C in Fig. 5. When constructing the pad, an attempt should be made to insert resistors as close to these values as possible; however, a slight deviation may be made without detrimental results. The resistors must be absolutely non-inductive to prevent frequency distortion.

The resistor values used in this example may be checked by setting up a circuit as in Fig. 6, then finding the total circuit resistance looking first from Z into the load, then looking from z into the source.

Example 3: What resistor values should be used for designing a "pi" pad to work between an input impedance of 200 ohms and an output impedance of 50 ohms to produce a loss of 24 db?

Solution: Table 10 gives the resistance values used when working between a source impedance of 200 ohms and a load impedance of 50 ohms. A "pi" pad is constructed as shown at D in Fig. 5, hence the resistor values given on the right side of table 10 should be used for designing this type of pad. To find the resistor values necessary, come down the db column on the right side of table 10 to the number 24. Then across on a horizontal line to the resistor values given in the columns on the right side of the table. The value for the input shunt resistor u is seen to be 228 ohms, the series resistor v 790 ohms, and the output shunt resistor w 53.2 ohms. Values reasonably close to these should be obtained in order to produce the desired attenuation and not introduce a mis-matched condition between the input and output impedances.

Like the "T" pad, a "pi" pad is unbalanced because equivalent series resistors are not contained on both sides of the line. If it is desired to balance a "pi" pad, the series resistor v is divided by 2, and the quotient obtained is the necessary number of ohms in series with each side of the line. The pad then becomes an "O" pad as illustrated at E in Fig. 5. Continuing, if it is desired to completely balance the "O" pad in all directions, the two shunt resistors "u" and "w" are cut in half, then the center of the pad between the two sides of the line is grounded as illustrated at F in Fig. 5.

The 24 db "pi" pad which we started with originally in this problem may be converted into an "O" or a balanced "O" pad by following the above procedure. The db loss is still 24 and the input and output impedances are still 200 ohms and 50 ohms respectively. If the original pad has been converted to a balanced "O", the size of the resistors will now be 114 ohms for each of the resistors marked u/2 at F in Fig. 5, 395 ohms for each of the resistors marked v/2 and 26.6 ohms for each of the resistors marked w/2. Non-inductive resistor values that are accurate within 5% of these values should be chosen in order to obtain the desired results.

Example 4: Design a balanced "O" pad to produce a 13 db loss between an input impedance of 250 ohms and an output impedance of 200 ohms.

Solution: Table 6 gives the resistor values to use between the combination of impedances as stated in the problem. The resistor values to start the calculations would be secured from the right side of the chart. For a 13 db loss, the values as taken from the table are found to be u = 297 ohms, v = 473 ohms, and w = 292 ohms. For a balanced "O" pad, each of these resistor values must be divided in half, and inserted in the circuit as illustrated at F in Fig. 5. Thus, each of the resistor values marked u/2 would have a value of 148.5 ohms, each of the v/2 elements would be 236.5 ohms, and each of the output shunt resistors marked w/2 would have a value of 146 ohms.

5. MINIMUM LOSS OF A PAD. In Example 4, it will be noted that table 6 does not have resistor values given for attenuation less than 13 db for the "pi" or "O" type pads. In the same table, resistor values are not given for "T" and "H" pads to produce an attenuation less than 6 db. Upon inspecting the other tables that do not have equivalent input and output impedances, namely, tables 2, 3, 4, 7, and 10, it will be found that resistor values are given for a minimum attenuation between 6 and 16 db. This leads to the conclusion that there is a definite limit on the minimum attenuation that can be produced between unequal source and load impedances. The reason for this is because upon calculating the resistor values, it is found that either the series or shunt resistor elements are found to have a theoretical resistance value below zero. Since the construction of such a resistive component for use in a pad is impossible, the minimum attenuation will be limited, dependent upon the type of pad employed and the ratio between the input and output impedances.

The chart in Fig. 7 enables us to determine exactly the minimum db loss, knowing the ratio of input to output impedance, or output to input impedance. In this table, the left column is designated Z1/Z2, Z1 being the larger impedance and Z2 being the smaller. Suppose, for example, that the input impedance (Z1) is 500 ohms, and the output impedance (Z2) is 250 ohms. The ratio of input to output impedance will then be 500/250, or 2. From the table in Fig. 7 we find that the minimum db attenuation for a fixed pad between these impedance values would be 7.67 db.

Z1/Z2	DB LOSS	Z1/Z2	DB LOSS
1	0	4	11.42
1.1	2.74	6	13.46
1.2	3.78	8	14.79
1.3	4.57	10	15.8
1.5	5.73	12	16.65
2	7.67	16	17.98
3	9.96	25	19.94

Fig.7 Minimum values of db loss for a pure resistance pad.

Next let us assume that the input impedance to a fixed pad is 500 ohms and the output impedance 5,000 ohms. The ratio of the larger (Z1) to the smaller (Z2) impedance is 5,000/500, or 10. For this impedance ratio, we can determine from Fig. 7 that the minimum db loss will be 15.8.

Since fixed pads of any type are seldom used to match between a small input impedance and a high output impedance, there are no tables given on the preceding pages of this lesson to satisfy such conditions. However, by using the formulas starting on Page 35 of this lesson, resistor values may be calculated for a fixed pad to work between a low source impedance and a high load impedance.

6. ISOLATION EFFECT OF A PAD. The isolation effect of a fixed pad upon the equipment with which it is used is extremely important in broadcast work. For example, let us refer to Fig. 8. A in Fig. 8 shows a vacuum tube V1 working through the impedance ratio of an output transformer into a 500-ohm line. If the impedance ratio of this transformer is 20 to 1, then the turns ratio will be the square root of the impedance ratio, or 4.47 to 1. The vacuum tube V1 is designed to deliver the correct amount of audio power at a minimum of distortion only when its plate circuit is loaded with an impedance of 10,000 ohms. If this impedance increases or decreases over an appreciable range, the operating characteristics of the tube will be changed to the extent that both frequency and harmonic distortion will be produced. The terminating end of the 500-ohm secondary line is shown connected to the primary of an input transformer, which is also designed to have an impedance of 500 ohms. If the line is of appreciable length, say 10 miles, the load on the secondary of the output transformer is not only the primary of the input transformer, but also the characteristics of the long line. If the impedance of the secondary load changes, the primary impedance of the output transformer will also change, thus

altering the operating characteristics of the tube supplying the A.F. power. Unless these variations occur over a range sufficiently great to change the primary impedance by more than 10%, no detrimental results will occur.

Let us assume that some unforseen condition occurs in the 10 mile telephone line which decreases the secondary load to 250 ohms. This causes the primary impedance to drop to 5,000 ohms, a decrease of 50%. On the other hand, if the telephone line should become open, the secondary impedance will be almost infinitely high and the primary impedance will probably rise to about 5 to 7 times normal. If such varying impedance conditions exist in the telephone line, the operation of the tube V1 will be affected seriously. This can be corrected to a great extent by inserting a pad in the telephone line to isolate the line impedance variations from the load on the tube.

B in Fig. 8 shows a 500-ohm pad inserted in the telephone line directly at the secondary of the output transformer. The resistance values chosen for this pad are sufficient to produce a loss of 10 db. The elements of the pad marked X have a value of 130 ohms and the shunt branch Y is 351 ohms. If the telephone line now becomes open, the load on the secondary of the transformer will rise to only X + Y + X, or 611 ohms, instead of to infinity as was the case with no isolating pad in the circuit.

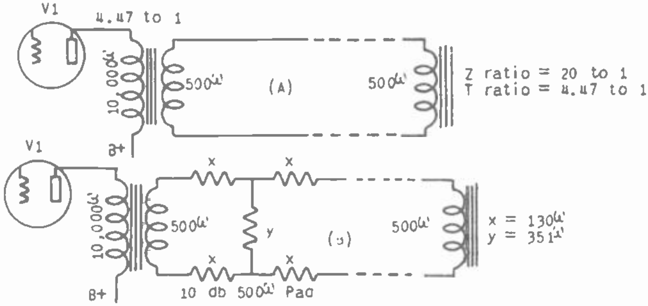


Fig.8 (A) Vacuum tube working into 500 ohm telephone line without pad. (B) 10 db pad inserted into line for isolation.

If the telephone line in B, Fig. 8 should be short circuited, a resistance of the shunt branch Y and the two series arms X on the right side would be in parallel. The two series arms on the right side and Y would produce an effective resistance of 144.4 ohms. This 144.4 ohms in series with two 130-ohm resistors on the left side of the pad produces a load of 404.4 ohms across the 500 ohm secondary. This is considerably different from the zero ohm load on the secondary that would result if no pad were used; consequently, the primary impedance does not drop appreciably. With the 10 db isolating pad, the total variation of the secondary impedance cannot differ more than 111 ohms from the 500 ohm value. This stabilizes the operation of the tube delivering audio power into the line and prevents the frequency and harmonic distortion. Using the 10 db pad, the secondary impedance variations reflected back through the turns ratio of the output transformer causes load variations on the tube from 8080 to 12,220 ohms, occuring at times of short and open circuit, respectively. Under normal operating conditions, such a wide change of secondary impedance would never occur. If the 10 db pad were not used, both the primary and secondary impedance values would change over an infinitely wide range when the line was opened and shorted. The beneficial effect of the pad is thus realized.

If there is a sufficient amount of audio power available from the vacuum tube, a greater isolation effect can be obtained by using an "H" pad designed with resistance values to produce a higher db loss. For example, if a 40 db loss could be tolerated, the resistance values for X and Y as determined from table 1 (and C of Fig. 5) would be 245 and 10 ohms respectively. Using these resistance values, if the impedance of the line changes from zero upon short circuit to infinity upon open circuit, the impedance variations across the secondary of the output transformer would be from only a few ohms above 500 to a few ohms below. This would maintain a virtually constant load on the vacuum tube delivering power into the line, regardless of the line impedance.

7. VARIABLE PADS. Numerous occasions arise in audio frequency circuits when it is desirable to change the audio energy level. In other words, it is frequently necessary to insert a device in the A.F. circuit to act as a volume control. Most of the volume controls that have been previously studied were simple potentiometers, used to vary the grid bias on a variable-mu tube or the grid exciting voltage to an A.F. amplifier. When inserted in constant im-

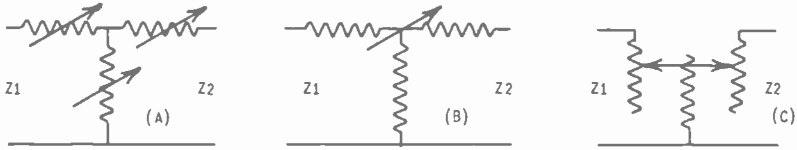


Fig.9 (A)(B)(C) Symbols generally used for a variable T pad.

pedance A.F. circuits, such as those for which fixed pads are designed, a potentiometer is not capable of maintaining either the correct source or load impedance. The impedance actually presented to both the load and source will depend upon the load and source impedances, the size of the potentiometer, and the extent of the attenuation. All these combine to make the simple potentiometer very unsatisfactory for use as an attenuation control between two fixed impedances.

The resistor elements in a "T" pad can be made variable and tapered in such a manner as to change the db attenuation, while maintaining a constant input and output impedance. To illustrate, let us refer to table 1 on Page 7. The resistors values necessary for the series and shunt arms of a "T" pad are given for db attenuation values from 1 to 70. Increasing db attenuation requires that the series elements, u and v, increase in value, whereas the shunt element w must decrease as the attenuation increases from 1 to 70 db. At each db level, all three arms must have a specific resistance value in order to maintain an input and output impedance of 500 ohms. This is accomplished in the construction of a variable "T" pad by properly tapering the three resistor elements. The attenuation range of a variable "T" pad seldom exceeds 40 db. To provide linear attenuation over a 40 db range, the resistor values specified in table 1 are exactly those which must be inserted in the circuit so as to maintain a constant input and output impedance of 500 ohms. Thus, the u and v series elements must change from 28.9 ohms at 1 db to 490 ohms at 40 db. Simultaneously with this change of the u and v elements, the shunt element w must decrease in value from 4,334 ohms at 1 db to 10 ohms at 40 db. To affect the db change over this range and still maintain a 500 ohm input and output impedance at each setting, the series and shunt resistor elements must be very accurately tapered.

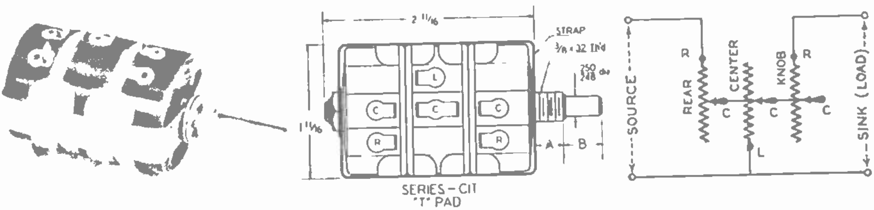


Fig.10 (A) Photograph of variable T pad. (B) Drawing to designate terminations on pad at A. (C) Symbol labeled to correspond with designations at B.

The symbol for a variable T pad may be drawn as at A, B or C in Fig. 9. A photograph of a constant impedance, wire-wound "T" pad control is shown at A in Fig. 10. B and C in Fig. 10 show the terminal wiring connections for the three variable resistors. The letters R, L, and C on drawings B and C refer to the right, left and center terminals, respectively, of the three tapered resistors. All three variable resistors are ganged on a common shaft. These controls are generally rated at a maximum power dissipation of from 1 to 2½ watts. They are not recommended for use in circuits where the operating level is higher than about plus 25 db.

Controls can be obtained for input and output impedances ranging from 15 to 1,000 ohms; higher values for specific requirements can generally be secured upon special order.

The attenuation and impedance curves for a typical "T" pad are shown in Fig. 11. The attenuation range is from 0 to 60 db over 100% rotation of the control. The sharp rise in the attenuation characteristic near 100% rotation is purposely introduced so as to provide a rapid decrease in the A.F. signal level when the control is being adjusted for zero output. The percentage deviation curve at the top of the graph in Fig. 11 shows the extent to which the input and output impedance vary over the attenuating range. In this typical characteristic, the impedance is shown to vary as much as 8% from the initial value of 250 ohms. More expensive pads are capable of maintaining the impedance characteristic more accurately.

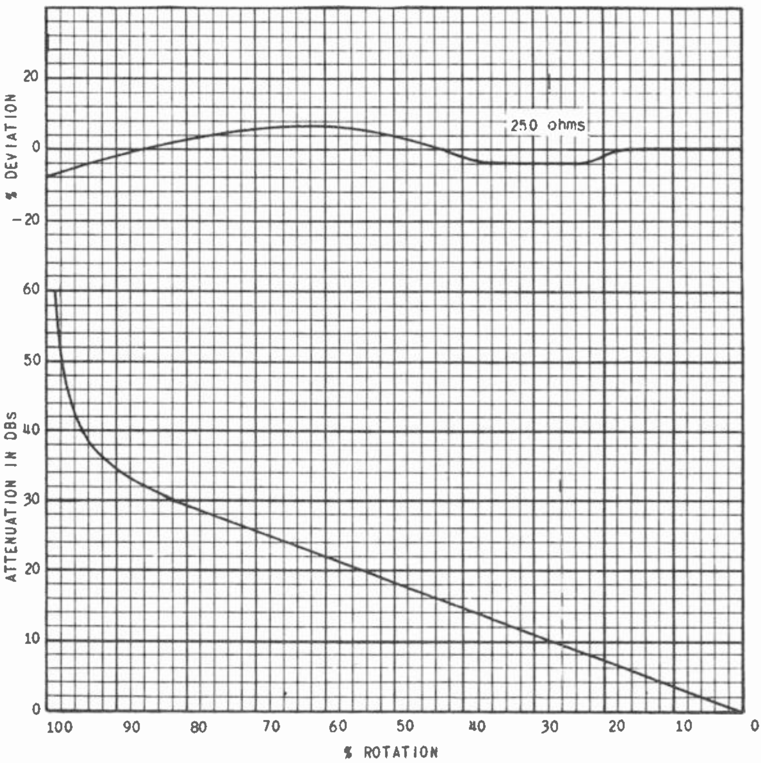


Fig.11 Attenuation and deviation curves for a typical T pad of the variable type.

For any type of variable pad to be satisfactory in high fidelity circuits, it should offer the same attenuation to all audio frequencies. Nearly all variable pads are designed so that no appreciable frequency distortion is introduced below 15,000 cycles. Electrostatic and electromagnetic shielding are generally provided when a variable pad is to be used in a low level A.F. circuit. A steel housing enclosing the unit is generally sufficient to accomplish this and, at the same time, protect the resistive elements from dust. In a shielded pad, a terminal strip, properly marked for making connections, is provided on the rear cover of the shield. The dial plate supplied with the unit is calibrated in dbs to correspond with the attenuation of the unit. The control knob has a fine pointer for accurate indication. Fig. 12 shows a front and rear view of a shielded T pad.

Variable H type attenuator controls are used in those circuits where it is essential that the two sides of the line be properly balanced. Such a condition must sometimes be satisfied by a master gain control when it is used in a mixer circuit such as illustrated in Fig. 14. An H attenuator can be thought of as consisting of two T attenuators having the center points connected together. The H attenuator is designed as though it consisted of two similar T attenuators, each having an input and output impedance equal to half the desired impedance values, and having the same attenuation as is desired from the actual H attenuator. The resistance values

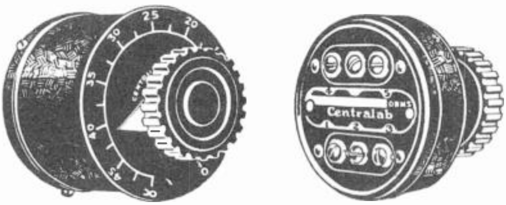


Fig.12 Enclosed T pad showing dial plate and terminal strips on rear.

to be used in the series arms would be ½ of those specified for T type attenuators.

The L type variable pads are employed as attenuation controls when a constant impedance is desired at either the source or the load, but not in both directions. They may be used in equipment where adequate control characteristics are necessary at an economical price and where high fidelity requirements must not be satisfied. L pads are generally designed for a continuous attenuation range from .5 to 40 decibels in 90% of the total rotation, then infinite attenuation is approached in the last 10% of rotation. L pads can be secured to match source impedances from 15 to 1,000 ohms. Higher

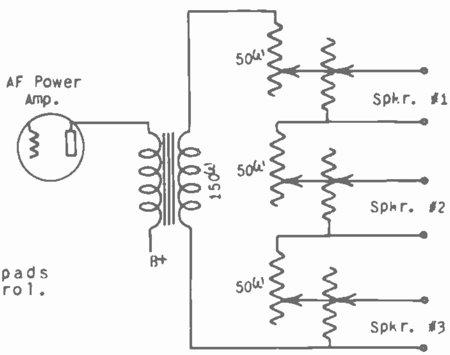


Fig.13 Method of using L pads for individual speaker control.

values of 10,000 ohms can be supplied upon special order. These controls may be used for controlling the grid excitation to an A.F. amplifying tube and can also be employed as individual volume controls for multiple speakers without affecting the load impedance on the audio power amplifier. A method of connecting L pads for individual speaker volume control is illustrated in Fig. 13.

A T pad attenuator is sometimes designed as shown at A in Fig.

14. At first glance this may appear to be an L pad; however, close inspection will reveal that there are two series and one shunt element in the attenuating unit. The variable arm X moves up and down over the resistors R1 and R2. In actual construction, these are two separate potentiometers with their shafts ganged so that one knob rotates both controls at the same time. That resistance between A and B serves as the left series element and the resistance

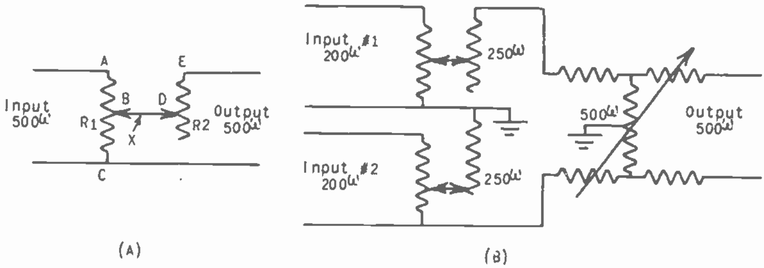


Fig.14 (A) Variable T pad using two resistive elements. (B) Mixer circuit using two T pads.

between D and E is the right series element. The portion of R1 between B and C serves as the shunt resistive element for a T pad circuit. To make certain that the input and output impedances remain constant, it is necessary to accurately adjust the taper of both R1 and R2. When properly designed, a T pad of this type will give exactly the same performance as those previously discussed.

B in Fig. 14 illustrates two T pads being used to mix the audio frequency output from two sources. Each T pad is designed for a 200-ohm input and a 250-ohm output. These impedance values will remain substantially constant, irrespective of the extent of the attenuation. The two T pads at B in Fig. 14 are connected in series, hence the total output impedance of the combination is 500 ohms. A variable H pad is then used to serve as a master gain control for both T pad attenuators. The input impedance of the variable H pad is designed for 500 ohms and the output impedance also remains constant at 500 ohms to deliver the A.F. energy into a 500 ohm load. It will be noticed that the center of the variable H pad is grounded and also the center connection between the two variable T pads is grounded. This practice is followed in most mixer circuits to reduce the electrostatic and electromagnetic disturbances to a minimum. A perfectly balanced system is obtained when it is grounded at the electrical center; the erratic line noises which may be picked up are then cancelled out.

8. GAIN CONTROLS AND FADERS. By using a variable pad arrangement as shown at B in Fig. 14, it is possible to mix the energy levels from the two A.F. sources in any desired proportion. For this reason, it is commonly called a "mixer" circuit, and the pads are sometimes called "mixers".

A "gain control" is the expression generally used in broadcast work to identify a high resistance potentiometer connected across the secondary of an input transformer for the purpose of controlling the grid excitation. Such a control is shown at A in Fig. 15. In the design of several commercial A.F. amplifiers, a control in this position is known as the "master gain control". The knob on the potentiometer shaft is mounted on the front panel of the amplifier and a dial plate, calibrated in dbs, is provided. The decibel calibration corresponds exactly to the audio output level from the amplifier.

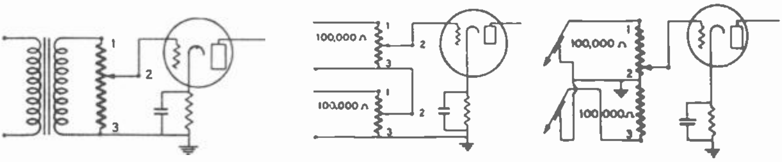


Fig.15 (A) Potentiometer used as gain control. (B) Mixer circuit using simple potentiometers. (C) Dual potentiometer used as fader.

Two potentiometers may be connected in series to mix the output of two high impedance audio sources, such as a crystal microphone and a crystal pickup. This is illustrated at B in Fig. 15. Since the grid impedance of the amplifying tube is infinitely high, a simple "mixer" circuit of this kind is satisfactory.

A "fader" is a dual potentiometer used to fade or change gradually from one A.F. source to another, generally between two phonograph pickup units. C in Fig. 15 shows how a fader is connected. When the arm is at point 1, the top pickup unit is feeding into the grid of the tube; when at point 3, the bottom pickup is in the circuit; at point 2, the grid is grounded and neither pickup can supply grid excitation. A mixture from the two sources is not possible with a "fader" control; it is used only for the purpose of obtaining a gradual and smooth change from one circuit to another. The dial plate supplied with a fader has 0 in the center (at ground) with increasing numerical divisions to the right and to the left.

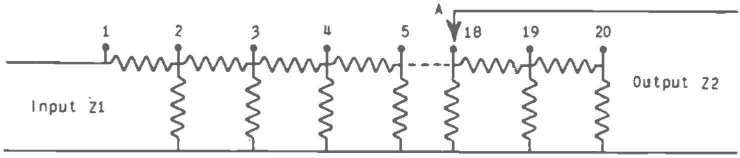


Fig.16 T type ladder attenuator.

9. **LADDER ATTENUATORS.** In recent years, a new type of attenuator known as a "ladder" attenuator has been developed specifically for broadcast use. A diagram to illustrate the fundamental construction of this type of variable pad is shown in Fig. 16. The unit does not employ a sliding arm to make direct contact with the resistance wire. Instead, it is constructed by assembling several small fixed resistor pads in a ladder formation, each single pad capable of producing a loss of about 2 db. At the inter-section between each of these small pads, a connection is made to a flat con-

tact surface on the rear of the assembled unit. The arm A revolves as the knob is turned to make connection with these individual contact surfaces. A photograph illustrating the construction of this type of control is shown in Fig. 17. The circuit is a modified T, unbalanced to ground, and has a fairly constant impedance over the attenuating range. Notice the contact buttons to which the fixed resistors are connected and the metallic ring for obtaining a continuous contact with the bottom side of the T pad circuit. Ladder

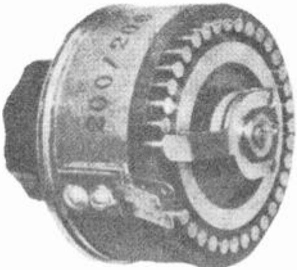


Fig.17 Photograph of ladder type T pad.

attenuators using L, T, and H pad circuits may be obtained. Also, many straight potentiometers are designed on the "ladder" principle; taps on the resistance wire are brought out to contact buttons instead of sliding the moving arm over the bare wire. The noise level of this type of control is extremely low.

In a ladder pad, the attenuation is not smooth from minimum to maximum, but instead is obtained in steps of about 2 db. Since the human ear is not capable of responding to a 2 db change in sound level, the variation will not seem "jerky" to the ear. Referring to Fig. 16, when the moving arm A makes contact with point 1, there will be no attenuation between the input and output impedances.

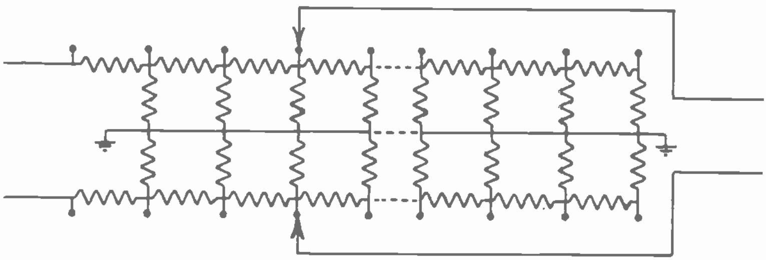


Fig.18 Internal wiring of a balanced H ladder pad.

Upon moving to point 2, a 2 db attenuation will be introduced; at 3, a 4 db attenuation; and so on to contact point 20, where a total attenuation of 40 db is introduced into the circuit. At each contact position of the wiping arm, the input and output impedances remain the same, as determined by the size of the small fixed resistors employed in the series and shunt branches. The fixed resistors are generally wound on small cylindrical spools which are an integral part of the bakelite mounting.

A balanced ladder type attenuator using fixed H pad sections is illustrated in Fig. 18. This type of attenuator control is typical of those employed in mixer circuits for broadcast station operation. The attenuator is perfectly balanced to ground, which reduces noise pickup and slight impedance variations to a minimum. The input and output impedances remain virtually constant over the entire attenuating range at all audio frequencies from 30 to nearly 20,000 cycles. In the balanced H ladder type attenuator, two sets of contact buttons must be employed. In some designs, both sets of contact buttons and both wiping arms are on the rear of the unit. In others, two separate sections are employed and ganged on a common shaft. These two methods of construction are illustrated in Fig. 19.

Fig.19 (A) Balanced H ladder pad using two sets of contact buttons. (B) Balanced H ladder pad using two ganged sections.

In high quality broadcast transmission, sound recording and reproduction, public address systems, or wherever accuracy, excellent frequency response and compactness are essential requirements, the balanced H type ladder attenuator will be found useful. The design of the individual resistors makes a very rigid mechanical construction. No slide wire contacts are used and the attenuating action is entirely step by step. The reliability of the attenuator is increased due to the absence of the slide wire contact. The level of the noise as introduced by a ladder control is much lower than could be obtained with the best of sliding contact attenuators. Mixing control panels, such as the RCA 46-A and 46-B, employ four such balanced H ladder type attenuators connected in parallel for the mixing circuit. Internal wiring of the units and photographs illustrating their construction will be given in the following lesson.

When selecting a variable pad for use in an A.F. circuit, there are several factors which should be taken into consideration. The first of these is the noise which is apt to be introduced into the electrical circuit. In this respect, the contact type of control is superior to the sliding wire type. Noise may be introduced by contact potential or by dust particles between the sliding arm and the resistance wire or contact button. Noise caused by contact potential results when the slider arm and wire, or the slider arm and contact buttons are made of different metals. Commercial variable pads are manufactured using sliding arms and contact buttons of such metallic alloys that the contact potential set up between them is reduced to a negligible value. To prevent noise from being introduced by dust particles, the attenuator should be contained in a dust proof shield, and cleaned at regular intervals. Carbon tetrachloride should be used for cleaning it. In broadcast stations, the variable pads in the mixing circuits are cleaned at least once a week, sometimes more frequently, depending upon the types of pads and the consistency of their use in the control room amplifying equipment.

Noise may be introduced into a variable pad by electrostatic and electromagnetic pickup in the resistance elements. The dust cover generally provides sufficient shielding to eliminate noise from this source.

The range over which attenuation may be produced is an important characteristic of a variable pad. Most variable pads cover a linear range from near zero up to about 35 or 45 db, then smoothly to infinity. If a contact type ladder pad is employed, the attenuation between steps should not be greater than 2 db. Some controls are made with 1½ db attenuation between each of the contact buttons. This permits a change in audio level to be made without it being noticeable immediately to the ear. The attenuation from minimum to maximum for any type pad should be linear as nearly as possible. If a graph were plotted showing db attenuation against percentage of rotation, (Fig. 11) a straight line should be obtained except near 100% rotation. This requirement is important because it enables the operator to produce an equivalent volume change for a given amount of rotation over the entire range of the variable pad.

The input and output impedance of a variable pad should remain substantially constant over the entire attenuating range.

A variable pad should offer the same attenuation to all audio frequencies when it is set to produce a given db attenuation.

Several types of typical mixer circuits, such as employed in broadcast station work, will be described in the following lesson.

10. TELEPHONE LINES AND THEIR CHARACTERISTICS. In broadcast station work, telephone lines are used to connect the studio with remote pickup points, to carry all chain or network programs, and to connect the studio with the transmitter when the transmitter is not located in the main control room. The telephone lines for remote broadcasts and the line connecting to the transmitter are leased by the broadcast station from the local telephone company on a contract or permanent rate basis. These leased wires do not pass through switchboards, but rather are permanently connected so as to be available for use at all times. In case of trouble on these leased lines, the local telephone company is responsible for the immediate location and remedy of the trouble.

The national, state, and sectional chain broadcast hookups are all installed and maintained by the American Telephone and Telegraph Company. The maps on Pages 24 and 25 show the networks of the National Broadcasting Company and Columbia Broadcasting System, respectively. The chain broadcasting companies make the necessary arrangements with A.T. & T. when they desire an outlet for their programs in a certain community through a local broadcasting station. The local station then receives the program from the local A.T. & T. office. The station is responsible for broadcasting the program (if contracted for) but the engineering personnel of the station has nothing to do with the maintenance of the incoming A.T. & T.

lines. The responsibility of the local station begins with the delivery of the program into its control room and all other technicalities are taken care of by the engineers of A.T. & T. and the chain broadcasting company.

The extensive use of telephone lines in radio broadcast work makes it necessary for an operator to be familiar with the characteristics of these lines in order that he may maintain high quality broadcasting with his equipment. The telephone lines that are leased from the telephone company are the same as those used for ordinary telephone conversation and normally have an average frequency response characteristic from about 200 to 2,900 cycles. This frequency range is sufficient to provide intelligibility for telephone conversations, but is entirely inadequate for radio broadcasting.

The common type of telephone line consists of two parallel or twisted copper wire conductors separated only by their insulation. A single line must have two wires and so is called a "pair". Several pairs are generally included in a single, lead covered cable. The smaller cables have 26 pairs contained within them; the larger cables have from 52 to 1818 pair. The wire size used may vary from 13 to 22 AWG. Insulation, consisting of a waxed paper covering, is used between the wires in a cable.

The proximity of the two wires and the fact that they are parallel to each other means that they will normally possess a certain amount of capacity between them. The two conductors have surface area facing each other and are separated by the insulation which serves as the dielectric. Since the construction of the line is generally uniform throughout its entire length, the capacity between the wires will be directly proportional to the length of the line. Thus, if the length of the line is doubled, or tripled, the total capacity between the two wires will increase in proportion.

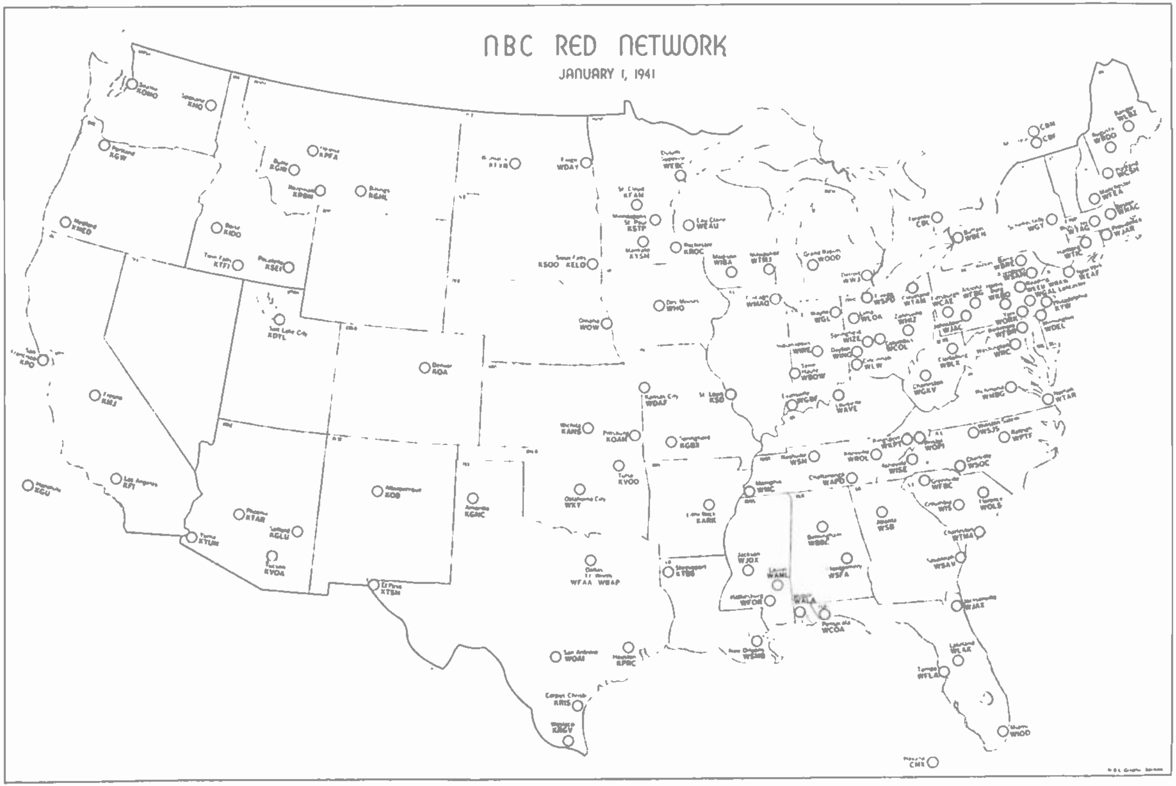
Telephone lines also possess a certain amount of inductance. Any current flow through a conductor sets up a magnetic field around it; this magnetic field in turn cuts the adjacent wire to produce the effect of inductance in the circuit. The effect of the inductance in the line is to hold back or retard the audio current variations, the reactance increasing directly with the frequency of the A.F. signal. The effect of the capacity distributed throughout the length of the line is to by-pass the audio signal as it travels through the wires, the same as the insertion of a fixed condenser would do. This by-passing effect increases toward the higher frequency end of the audio spectrum because of the decreased capacity reactance to these higher frequencies. Since all conductors possess resistance, a certain amount of attenuation in the line will also be due to the pure resistance which it possesses. The opposition offered by the pure resistance will be the same at all audio frequencies.

The attenuation of a telephone line depends upon its distributed inductance, distributed capacity, and ohmic resistance. Since both the inductance and capacity are reactive components, it follows that the attenuation will vary with the frequency.

Of the three attenuating factors in a telephone line, the distributed capacity is by far more predominant, and thus is more ef-

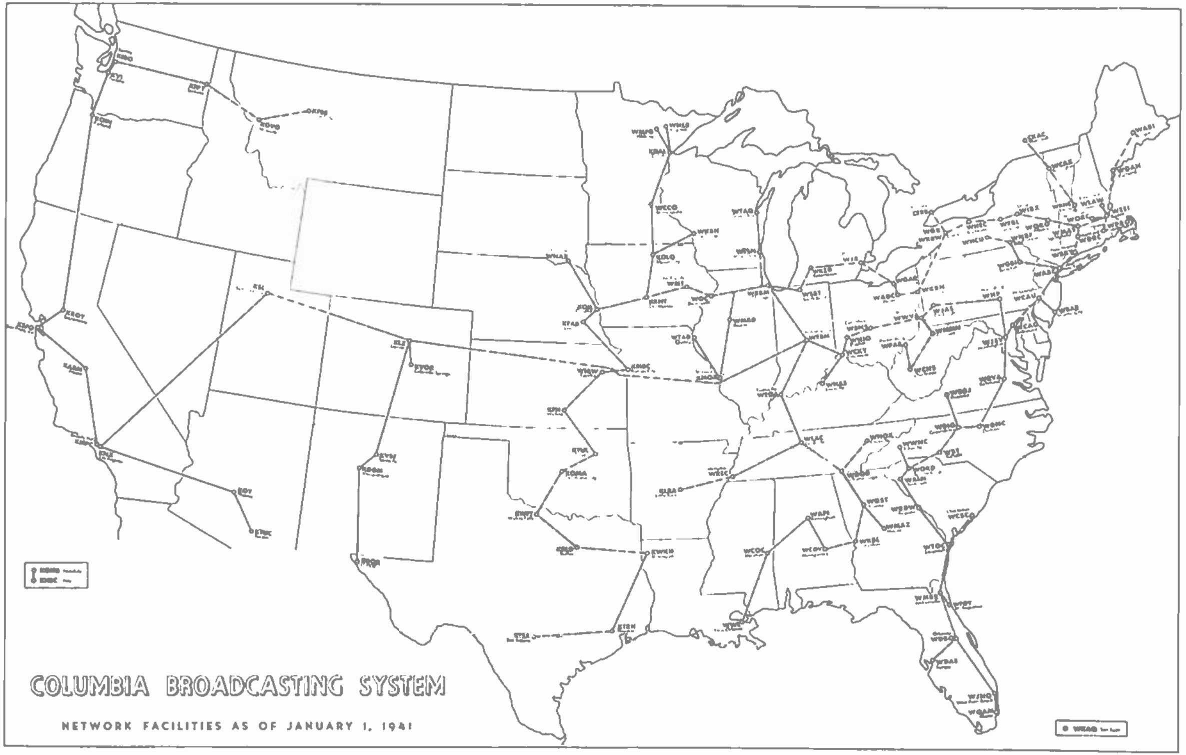
Map of the Red Network of National Broadcasting Company

(As of January 1, 1941)



Map of Network of Columbia Broadcasting System

(As of January 1, 1941)



fective in producing unequal attenuation over the audio frequency range. Fig. 20 illustrates how the inductive, capacitive, and resistive components are distributed throughout the length of a telephone line. If audio frequency energy of constant amplitude, but variable in frequency, is delivered to the input terminals at A, and

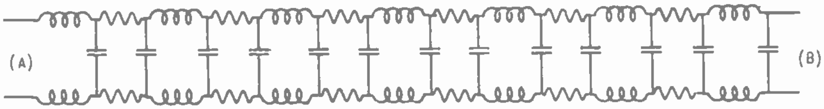


Fig. 20 Illustrating the distribution of inductance, capacity and resistance in a wire line.

a measuring device connected across the terminating end of the line at B, it will be found that the attenuation of the line is not equal at all audio frequencies. The higher frequencies are attenuated most, due to the effect of the predominating distributed capacity. In other words, the measuring device connected across the line at B will indicate more attenuation of the line at the higher audio frequencies than at the lower audio frequencies.

A.W.G. CABLE GAUGE	R OHMS	L HENRYS	C MICRO-FARADS
22	171.0	.001	.073
19	83.2	.001	.062
16	42.2	.001	.062
13	21.4	.001	.062

Fig. 21 Chart showing the distributed constants of a telephone line 1 mile long, at a frequency of 796 cycles.

The chart in Fig. 21 gives the constants of a one mile telephone cable for four different wire sizes. The measurements were made at 796 cycles. It should be understood that the inductive and capacitive components of the line are equally distributed throughout the entire length of the line and cannot be considered as "lumped" values. Notice from the table that the smaller size wire not only produces more resistance in the line, but also causes a higher distributed capacity. Since the inductance is dependent more upon the separation between the wires than it is upon the wire size itself, this value remains constant for the different size cables.

A short telephone line (less than a mile in length) would have a fairly flat frequency response from 100 to 5,000 cycles. However, a short line is seldom required in radio broadcast work, and as the line increases in length, the higher frequencies are attenuated more and more. The attenuation produced by the pure resistance in a line using #19 gauge wire is approximately .2 db per mile. This resistance loss remains constant over the entire audio range, and is directly proportional to the length of the line. The additional attenuation due to the capacitive component is approximately 1.1 db per mile at 1,000 cycles. This latter attenuation increases with both frequency and length of the line. The total attenuation of a #19 cable line one mile long is about 3.25 db at 5,000 cycles and approximately 4.5 db at 10,000 cycles. To be satisfactory for radio broadcasting, a telephone line should produce equal attenuation over a range of audio frequencies extending at least from 50 to 7,000 cycles. For high fidelity broadcasting, this range should be widened to from 30 to 10,000 cycles. To meet with this requirement, it is necessary to insert adjustable filters called "equalizers" in the telephone line.

To reduce line loss, the telephone company engineers often insert fixed series inductances in long telephone lines. This purposely introduced inductance tends to counteract the predominating effect of the line's inherent capacity and thus decrease the total audio power loss in the line. These coils are called "loading coils", and a line in which they are used is called a "loaded cable". Before a telephone line can be equalized to carry a high quality broadcast program, these loading coils must be removed.[1] The telephone company engineers will take the loading coils out of the line when it is necessary.

11. **LINE EQUALIZERS.** An equalizer consists of a resonant circuit, having an adjustable resistance in series. When properly adjusted, an equalizer will attenuate or filter the lower audio frequency notes in exactly the same proportion as the telephone line attenuates the highs. In this manner, the db attenuation can be made constant over a given audio frequency range and the radio program reaching the terminating end of the line will be an exact,

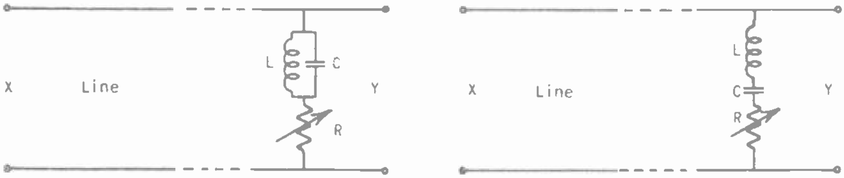


Fig. 22 (A) Parallel equalizer circuit. (B) Series equalizer circuit.

although attenuated, reproduction of the program fed in at the source end. In other words, an equalizer when properly designed and adjusted, will compensate for the normal frequency distortion that occurs due to the capacity distributed throughout a telephone line.

A parallel resonant equalizer circuit is shown at A in Fig. 22. The coil L possesses a very low ohmic resistance and is resonant with the condenser C at a frequency slightly higher than the maximum to which the line is to be equalized. If the line is to be equalized to 5,000 cycles, the capacity and inductance values selected should produce resonance around 5,500 or 6,000 cycles. For equalization up to 10,000 cycles, the parallel resonant circuit

[1] Recently, loaded cable circuits have been designed to possess satisfactory frequency characteristics up to 8,000 cycles. They are being used mainly to carry network programs. Formerly, network lines were equalized to only 5,000 cycles.

should have L and C values which will produce resonance at about 10,500 or 11,000 cycles. The adjustable resistor R is connected in series with the parallel resonant circuit and the combination placed across the line as shown.

Important characteristics of a parallel resonant circuit are that it offers a very high impedance to the resonant frequency, a relatively high impedance to frequencies close to resonance, and a low impedance to frequencies considerably below and above its resonant point. As the frequency of the A.F. voltage applied across a parallel resonant circuit drops below resonance, the shunt impedance offered by the tuned circuit becomes lower and permits the low frequencies to pass through it. At A in Fig. 22, the low frequencies will by by-passed around the line termination at Y by the low impedance of the equalizer circuit. The resultant level of the low audio voltages will be governed mainly by the setting of the resistor R. Upon adjusting this resistor, the equalizer can be made to

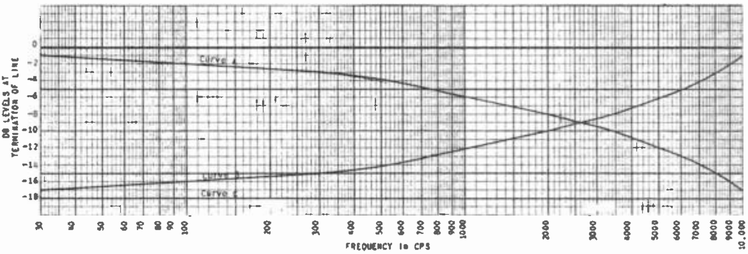


Fig. 23 Graph illustrating line attenuation, equalizer attenuation, and total attenuation of an equalized line at different audio frequencies.

control (within limits) the overall frequency response of the line. Above the resonant frequency of the parallel tuned circuit, the low impedance provided by the capacitive branch adds to the distributed capacity of the line and the total attenuation at the higher audio frequencies will be due to the additive effect of the equalizer's capacity and the line's distributed capacity. For this reason, it is not possible to equalize a line for audio transmission higher in frequency than the resonant frequency of the inductance and capacity in the equalizer circuit.

The function of an equalizer may be explained by reference to the graph shown in Fig. 23. Curve A illustrates the attenuation due to the distributed capacity of the line at audio frequencies between 30 and 10,000 cycles. It will be noted that at 30 cycles, the attenuation is only 1 db, this being due mainly to the resistance of the line. At 10,000 cycles, the attenuation of the line is 17 db. If the line were left unequalized and a radio program transmitted over it, the program would suffer serious frequency distortion. Curve B in Fig. 23 shows the characteristic curve of the equalizer when it is properly adjusted. The series resistance in the equalizer is set to such a value that the attenuation at 30 cycles is 17 db. This is equivalent to the attenuation produced by the line at the highest audio frequency. The characteristic curve of the equalizer is made exactly opposite the curve of the line by properly adjusting the resistance, capacity, and inductance values. Since the overall attenuation at any frequency will be equal to that produced by both the equalizer and line, it can be made constant over the entire audio range as illustrated by line C in Fig. 23.

The insertion of an equalizer across a telephone line will always result in a lower db output from the line than would exist if the equalizer were not present. In other words, the total attenuation is increased; however, the objective of the equalizer is not to prevent attenuation, but rather to equalize the attenuation so that it drops the db level at each audio frequency to the same value. The high overall attenuation makes it necessary to employ additional audio amplification at the termination end of the line. However, this should not be classified as a disadvantage, because the beneficial effect of the equalizer in preventing frequency distortion is by far more important.

Whereas the curves in Fig. 23 are comparatively smooth and the overall attenuation curve is absolutely flat from 30 to 10,000 cycles, it will be found that in actual practice, this idealistic condition is seldom obtained. When equalizing, an attempt is made to flatten the overall characteristics of the line so that it does not vary more than plus or minus 2 db over the complete frequency range. Variations in sound energy level of 2 db or less are not noticeable to the human ear and thus the slight frequency distortion that does exist will not be apparent.

B in Fig. 22 shows a series resonant equalizer connected across the terminating end of a telephone line. This type of equalizer circuit has opposite characteristics to those of the parallel type. At the resonant frequency, it produces a low impedance and functions as an attenuating device. At frequencies above and below resonance, the series equalizer circuit offers a high impedance to the passage of audio signals through it. When the reactances of L and C are equal, they cancel each other and the series resistor R is the only opposition to the passage of audio energy through the equalizer circuit. The A.F. energy that passes through the equalizer circuit will not appear across the output terminals at Y.

The curves in Fig. 24 illustrate the effect of a series equalizer circuit. In this case, the telephone line is assumed to have an excessive output at frequencies in the vicinity of 60 cycles. Excessive output at certain audio frequencies produces frequency distortion the same as an insufficient output. By placing a series equalizer circuit across the line and adjusting the inductance, capacity, and resistance components to the correct value, an effect may be obtained with the equalizer that is opposite the normal characteristic of the line. The overall result will be a frequency response curve that is fairly flat throughout the entire audio range. The line, equalizer, and overall curves in Fig. 24 are shown somewhat irregular. This illustrates the results that would most likely be obtained when actually plotting the frequency response curves.

Excessive response at certain frequencies is rather unusual in a telephone line; however, the line's distributed capacity will invariable produce a decreased output at the higher end of the audio spectrum. Thus, the need for a series resonant equalizer circuit is very rare in broadcast work, but a parallel resonant circuit must be employed across all telephone lines of appreciable length when they are used to carry radio programs.

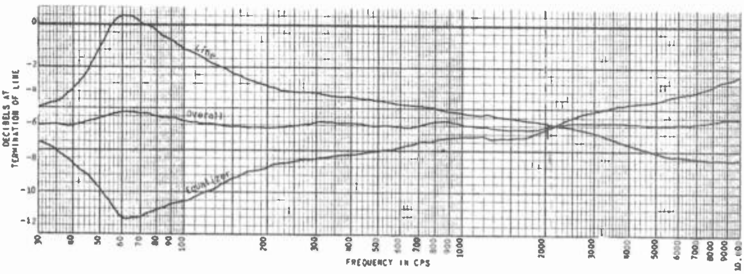


Fig.24 Graph illustrating the characteristics of a series equalizer circuit.

It is possible to connect a parallel resonant equalizer circuit across a line at any point; however, it is considered much better practice to use the equalizer at the terminating or receiving end of the line. At the line's termination, the quality of reception will be judged, and emergency conditions which might require a readjustment of the equalizer circuit, can most conveniently be taken care of. Also, with the equalizer at the terminating end, any low frequency noises that might be picked up by the line will be attenuated by the equalizer.

When ordering a broadcast line from the telephone company, a request should be made to obtain a pair of wires in or near the center of the cable. The lead covering surrounding the many pairs in the cable is always grounded, so if a center pair is obtained, the pair of wires will have equal capacity with respect to each other, to the remaining wires in the cable, and to the lead shield. This capacity-balanced condition will greatly assist in reducing the inductive and static line noises. If not properly balanced in this manner, interference is apt to result from telephone conversations on adjoining pairs, from dial phones, and from ringer noises. To be satisfactory for broadcast use, the inherent line noise must be extremely low.

12. **EQUALIZING A TELEPHONE LINE.** When a telephone line is used for connecting between the studio and the transmitter, the line is equalized at the time the broadcast station equipment is installed and needs no further attention except an occasional check to make sure that its characteristics have not changed. The equalizer is always placed at the transmitter end of the line. A check on the frequency response of the line can be made by feeding an audio oscillator into the line at the studio, then watching the reading of a db meter connected across the output of the line at

the transmitter. If the control room operator keeps the level of the audio oscillator constant at the studio, the transmitter engineer may record the db readings at the terminating end of the line. By collecting data at several audio frequencies, a graph may be plotted to indicate the line characteristics.

Most of the equalizing done in broadcast station work will be in connection with the remote pickup points. The remote lines are leased from the telephone company on a monthly or weekly basis. As the program seasons change, the remote lines will be taken out or installed according to the directions from the management of the station. Whenever a new remote line is installed, it must be equalized before it can be used to carry a radio program. The audio oscillator that is used for the equalization should be capable of covering the entire audio range and the harmonic content in the oscillator signal should be negligible.

Either one of two procedures may be used to equalize a remote telephone line. Fig. 25 shows the equipment set up for the first of these. The audio oscillator and remote amplifier are transported to the remote point and connected to the telephone line through an isolating pad. The complete set-up is shown on the left side in Fig. 25. Of course, the audio oscillator could be fed directly into the line instead of through the remote amplifier. However, by using the set-up illustrated, it will be possible to adjust the

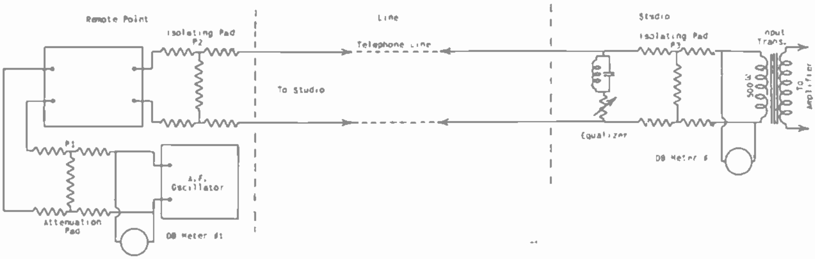


Fig.25 Block diagram to illustrate the equipment arrangement for equalizing a telephone line.

equalizer to compensate for frequency distortion in the remote amplifier as well as in the line. The attenuating pad P1 connected between the A.F. oscillator and the remote amplifier is for the purpose of reducing the oscillator output until the signal is equivalent to that of a microphone feeding to the input of the amplifier. At the studio end of the telephone line, the equalizer is connected in shunt with the line by the control room operator, an isolating pad (P3) is inserted, the line is properly terminated in a 500 ohm load, and a db meter is connected across the primary of the input transformer.

With this arrangement, the operator at the remote control point adjusts the audio oscillator for various frequencies throughout the audio range and keeps the input to the remote amplifier constant by changing the gain control on the A.F. oscillator. Db meter #1 provides a reading so that the A.F. signal may be kept at the same value for each frequency. The constant amplitude A.F. signal is fed through the remote amplifier, isolating pad, and telephone line to the studio. The operator at the control room makes note of the readings obtained on db meter #2. Until the equalizer is inserted across the line, it will be found that the db readings on #2 gradually drop off toward the high frequency end of the audio range. After preliminary observations have been made in the line, the equalizer should be connected and different resistance values inserted experimentally until db meter #2 remains practically constant at all frequencies fed from the remote point. To obtain satisfactory equalization, it is necessary to go back and forth over the audio range several times. Equalization is strictly an experimental procedure and should be continued until the best setting of the variable resistance in the equalizer circuit is obtained. The overall line characteristic must be made sufficiently flat to enable the transmission of a radio program without introducing serious frequency distortion.

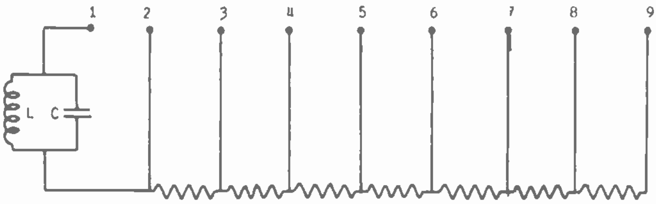


Fig. 26 Diagram of Western Electric 23-A Equalizer.

The Western Electric 23A equalizer, suitable for connection across the studio end of a remote line, is shown in Fig. 26. The parallel circuit is resonant at approximately 9,400 cycles. Several resistance values are placed in series with taps brought out at each inter-connection so that a wide variety of resistor values is available. It will be the duty of the operator at the control room to insert the proper amount of resistance in series with the equalizer circuit so that the response of the line may be made flat over the required range. Commercial equalizers are mounted on a standard 19" panel so that the unit may be permanently inserted in the rack containing the other components of the speech input equipment. Fig. 27 shows a United Transformer Company Model 3A equalizer. On the front of the equalizer panel, calibrated dials are provided to indicate the resistance value inserted in the equalizer circuit. If a variable and calibrated equalizer is not used, the operator must experiment with the plug-in resistor arrangement illustrated in Fig. 26 until the proper series, parallel, or series-parallel combination is obtained.

The word "NEMO" is commonly used by broadcast engineers to designate a remote pickup point or a remote broadcast. The telephone company is always instructed to install at least two separate telephone lines for a remote (NEMO) broadcast. One line is used to carry the radio program and the other is used for communication between the studio and the remote point. Various terminologies are used to designate these two lines; the student should be familiar with them. The broadcast line is frequently called, "the radio line", the "program line", or the "broadcast loop". The line used for communication between the control operator and the remote operator may be called the "talking line", the "talk-back circuit", the "mag (magneto) line", or the "order wire line". Perhaps "broadcast loop" and "order wire line" are the two most commonly used expressions.

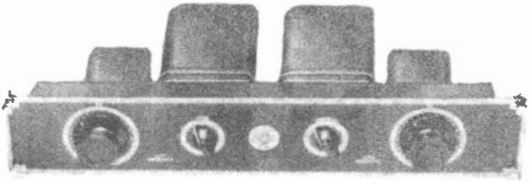


Fig.27 Model 3A United Transformer Co. equalizer.

Both the broadcast loop and the order wire line are permanently installed to the remote point and are available at all times for use by the broadcasting station. The purpose of the order wire line is to enable communication between the operator at the remote point and the operator at the main control room before, during, and after the remote broadcast. Orders pertaining to the broadcast and time checks are given over the order wire line so that the broadcast from the remote point may be put on the air as efficiently as possible. The order wire line may also be used for equalizing, as will now be explained.

Fig. 28 shows the equipment set up for equalizing the broadcast loop in a slightly different manner from that previously explained. With this arrangement, the audio oscillator is left in the control room, permanently mounted as a part of the speech input equipment. This is advisable because the oscillator will maintain its calibration much more accurately if it is not being moved away from the station to a remote point whenever a line is to be equalized. As shown in Fig. 28, the output of the audio oscillator is fed through the order wire line to the remote point. At the remote point, the output of the order wire line is connected to the input of the remote amplifier through an isolating and attenuating pad. The output of the remote amplifier is then connected through a pad to the broadcast loop, and the A.F. signal is delivered back to the studio. The equalizer, isolating pad, terminating impedance and db meter are connected across the broadcast loop at the control room. The operator who has taken the remote amplifier to the remote point has only one job to perform, that of keeping the audio level as fed into the remote amplifier at a constant value. Using the arrangement shown in Fig. 28, the variable H pad is adjusted so that each frequency fed through the order wire line is delivered into the remote amplifier at the same value. Db meter #1 is used to keep the input level constant. The gain control on the remote amplifier is then set to the approximate level that will be used during a broadcast. Frequency distortion in both the remote amplifier and the broadcast loop will be corrected by properly setting the equalizer at the studio. After equalizing the broadcast loop, the equipment may be changed over and used to at least partially equalize the order wire line. The equalizer will be permanently connected across the broadcast loop; however, in case of emergency, the order wire line may be used to carry the radio program if the proper equalizer setting has been pre-determined. It will only be necessary to change the equalizer to the order wire circuit and insert the proper resistance when the occasion arises.

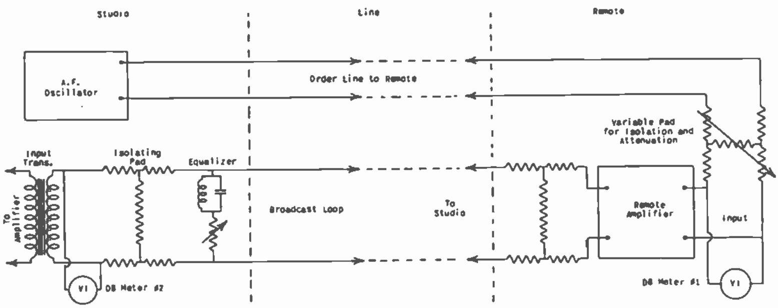


Fig.28 Equipment arrangement for equalizing, using the order wire line.

For rapid and efficient equalizing, the system shown in Fig. 28 is perhaps superior to the procedure previously described. The reason for this may be attributed to the fact that one operator in the main control room has both the oscillator and equalizer at his immediate command. By watching the db meter, it is easy for him to change the frequency of the oscillator over the audio range and determine the characteristics of the line very quickly. Then for each equalizer adjustment which he makes, he has only to reach over, change the frequency of the audio oscillator, and by watching the db meter, note the results of his change. Having all controls and the db indicator before him, the operator may rapidly and efficiently complete the equalizing procedure.

While equalizing a line, it is necessary for the operators to keep in mind the fact that the telephone company will not permit a level higher than plus 2 db to be fed into their lines. Should this be done by accident, it is very likely to cause considerable interference on the other telephone lines contained in the cable with the broadcast loop and order wire line. In general, all telephone lines should be fed at an audio level of 0 db with occasional peaks not exceeding plus 2 db.

If long telephone lines are used, "booster" amplifiers must be inserted at intervals when the line level falls to -25 db at the highest audio frequency. After a broadcast signal has traveled over several miles of telephone wire, it becomes attenuated to the point where the line noises closely approach the level of the radio program. Cross - talk from neighboring telephone lines is then apt to cause interference on the broadcast line. The booster amplifier is used merely for the purpose of increasing the level of the broadcast signal so that such interference and cross-talk will not occur.

These booster amplifiers are frequently called "repeater amplifiers" or simply "repeaters". They are supplied by the telephone company as a part of its service and the broadcast station personnel has nothing whatsoever to do with the installation and maintenance. These amplifiers are generally built to possess an excellent frequency response; however, their frequency characteristics must be taken into consideration when equalizing the broadcast line. The overall response of the line and booster amplifier should be adjusted until it is reasonably flat over the required audio range.

FORMULAS FOR RESISTANCE PAD CALCULATIONS

To provide a mathematical means of calculating the resistance values necessary for fixed pads of the L, T, and H type, the following formulas are given. It is understood that only those students proficient in the use of logarithms and algebra are to study this discussion. Throughout these formulas the input impedance to the pad will be designated as Z1 and the output impedance as Z2.

In order that the extent of attenuation in db will be taken into consideration, a factor K must be employed in each formula.

$$K = \text{Antilog} \frac{db}{20} \qquad (1)$$

where db is the attenuation desired through the pad in decibels.

Fig. 1 at A shows a T pad with the resistor elements labeled R1, R2, and R3. First let us say that Z1 = Z2, that is the input and output impedances are equal. Then R3 will be equal to R1 and:

$$R1 \text{ (also } R3) = Z1 \left(\frac{K - 1}{K + 1}\right) \qquad (2)$$

$$R2 = Z1 \left(\frac{2K}{K^2 - 1}\right) \qquad (3)$$

For an H pad working between equal impedances, the values for R1 and R3 are figured in the same manner, (equations 2 and 3) then cut in half and inserted on opposite sides of the line. This is shown at B, Fig. 1.

If a Pi (π) section is desired between equal impedances for Z1 and Z2, the values for the series arm R1 and the two shunt arms R2 and R3 are calculated using formulas (5) and (6) as follows:

$$R1 = \frac{Z1}{2} \left(\frac{K^2 - 1}{K}\right) \qquad (5)$$

$$R2 \text{ (and } R3) = Z1 \left(\frac{K + 1}{K - 1}\right) \qquad (6)$$

Where R3 has the same value as R2.

For an O pad (D in Fig. 1) the values for R2 and R3 remain the same as in a π pad but the value for R1 is cut in half. Find R1 and R2 with formulas (5) and (6). An L pad (E in Fig. 1) to work between equal impedances (Z1 = Z2) may be designed using the following formulas. These apply in cases where the impedance is matched at the series resistor end of the pad.

$$R1 = Z1 \left(\frac{K - 1}{K}\right) \qquad (7)$$

$$R2 = Z1 \left(\frac{1}{K - 1}\right) \qquad (8)$$

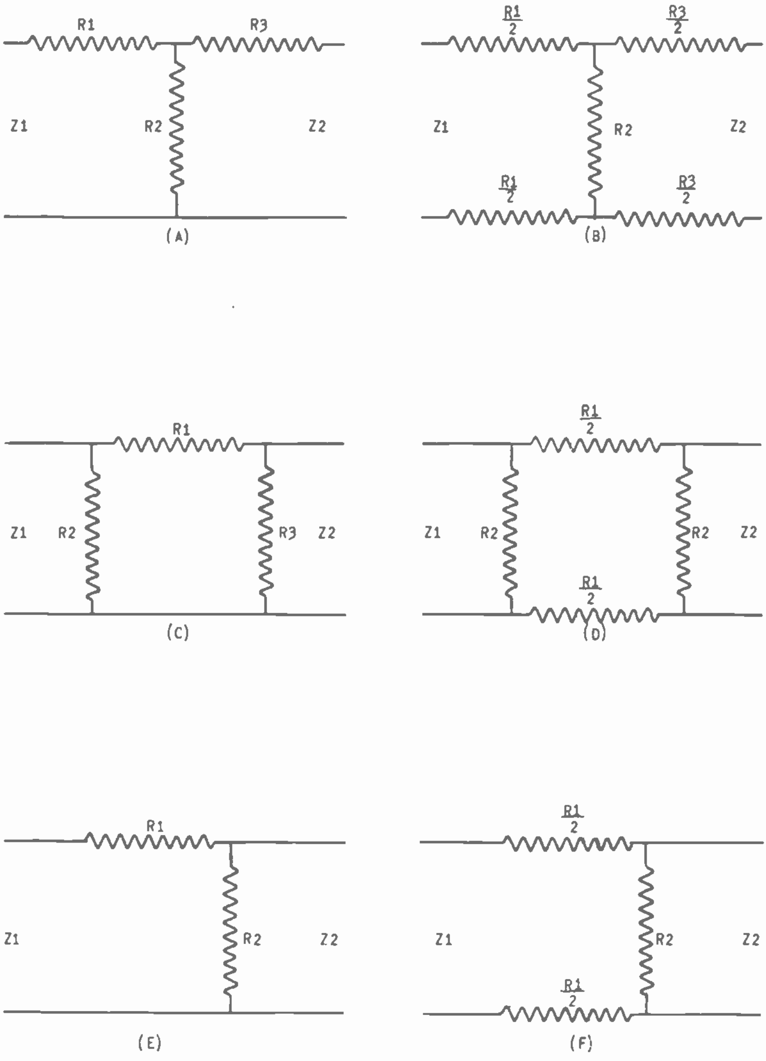


Fig.1 Diagrams of fixed pads that are used as references in the formulas starting on page 35.

For a U pad (F in Fig. 1) between equal impedances, R2 remains the same, but the value of R1 is cut in half. Find R1 and R2 with formulas (7) and (8).

Let us work an example to illustrate the use of these formulas. Find the resistor values to use between equal impedances of 500 ohms for a T pad to produce a 30 db loss. First find K from formula (1).

$$K = \text{Antilog}\,\frac{db}{20} = \text{Antilog } 1.5 = 31.6$$

Using formula (2) to find R1 and R3:

$$R1 = Z1\left(\frac{K-1}{K+1}\right) = 500\left(\frac{31.6-1}{31.6+1}\right) = 500\left(\frac{30.6}{32.6}\right)$$

$$= (500)\ (.938) = 469 \text{ ohms.}$$

$$R2 = Z1\left(\frac{2K}{K^2-1}\right) = 500\left(\frac{2\times 31.6}{31.6^2-1}\right)$$

$$= 500\left(\frac{63.2}{999}\right) = (500)\ (.0632) = 31.6 \text{ ohms.}$$

To check these calculations, refer to the proper columns in Table 1. A difference of only .4 ohm exists in the shunt branch.

The formulas for the π and O pads can be checked against the table in the same manner. A difference of a few ohms may exist between the formulas and the tables, due to the accuracy of computation. To design resistance pads for insertion between unequal impedances ($Z1 \neq Z2$) the following formulas are used:

(1) T pad between unequal impedances:

$$R1 = Z1\left(\frac{K^2 + 1 - \frac{2K}{S}}{K^2 - 1}\right) \quad (9)$$

$$R2 = \frac{2Z1}{S}\left(\frac{K}{K^2 - 1}\right) \quad (10)$$

$$R3 = Z2\left(\frac{K^2 + 1 - 2KS}{K^2 - 1}\right) \quad (11)$$

where:

Z1 is the input impedance,
Z2 is the output impedance.

$$K = \text{Antilog}\,\frac{db}{20}$$

$S = \sqrt{\frac{Z1}{Z2}}$ or $\sqrt{\frac{Z2}{Z1}}$ The ratio of input and output impedance should always be greater than 1, so the larger impedance value is used for the numerator.

For H pads, R1 and R3 are cut in half and the equal values placed on opposite sides of the line.

(2) Pi pad between unequal impedances:

$$R1 = \frac{Z1}{2S}\left(\frac{K^2 - 1}{K}\right) \quad (12)$$

$$R2 = Z1\left(\frac{K^2 - 1}{K^2 - 2KS + 1}\right) \quad (13)$$

$$R3 = Z2\left(\frac{K^2 - 1}{K^2 - 2\frac{K}{S} + 1}\right) \quad (14)$$

where:

$$K = \text{Antilog}\,\frac{db}{20}$$

$$S = \sqrt{\frac{Z1}{Z2}} \text{ or } \sqrt{\frac{Z2}{Z1}}$$

For an O pad, the value of R1 is cut in half and inserted in opposite sides of the line.

L pad between unequal impedances: (when impedance is matched in direction of series arm).

$$R1 = \left(\frac{Z1}{S}\right)\left(\frac{KS - 1}{K}\right) \qquad (15)$$

$$R2 = \left(\frac{Z1}{S}\right)\left(\frac{1}{K - S}\right) \qquad (16)$$

where K and S are the same as before.

Let us solve an example to illustrate these types of problems. If a 20 db T pad is to be inserted between a Z1 of 500 ohms and a Z2 of 250 ohms, what must the values be for R1, R2, and R3?

First find K and S.

$$K = \text{Antilog}\ \frac{db}{20} = \text{Antilog}\ 1 = 10$$

$$S = \sqrt{\frac{Z1}{Z2}} = \sqrt{\frac{500}{250}} = \sqrt{2} = 1.414$$

Substituting in formula (9) for R1:

$$R1 = Z1\left(\frac{K^2 + 1 - \frac{2K}{S}}{K^2 - 1}\right) = 500\left(\frac{100 + 1 - \frac{(2)(10)}{1.414}}{100 - 1}\right)$$

which is equal to:

$$500\left(\frac{101 - 14.2}{99}\right) = (500)(.877) = \underline{438.5 \text{ ohms} = R1}$$

Substituting in formula (10) for R2,

$$R2 = \frac{2Z1}{S}\left(\frac{K}{K^2 - 1}\right) = \left(\frac{1000}{1.414}\right)\left(\frac{10}{99}\right)$$

$$= (707)(.101) = \underline{71.4\omega = R2}$$

Substituting in formula (11) for R3,

$$R3 = Z2\left(\frac{K^2 + 1 - 2KS}{K^2 - 1}\right) = 250\left(\frac{100 + 1 - (20)(1.414)}{99}\right)$$

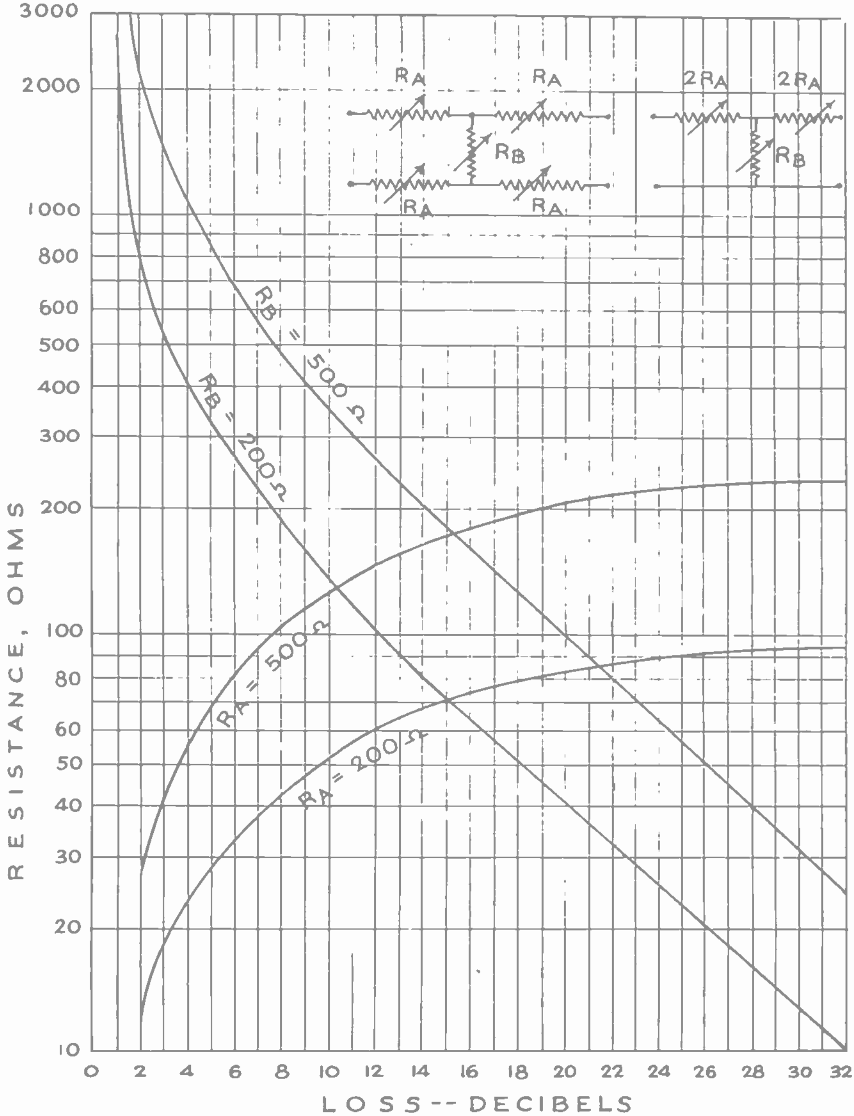
$$= 250\left(\frac{101 - 28.2}{99}\right) = (250)(.735) = \underline{183.7\omega \text{ for R3.}}$$

It will be found that these resistor values check very closely with those given in table 2 on page 7.

The minimum loss for which T and π pads can be designed between unequal impedances occurs when the resistance network becomes an L pad. A T pad becomes an L pad when R3 = 0 and a π becomes an L pad when R3 = infinity (∞). This will occur when:

$$K = S + \sqrt{S^2 - 1}$$

An L pad is limited in minimum attenuation when R2 becomes infinity (∞). This results in R1 acting as the sole element in series (no shunt element) and occurs when K = S.



Proper attenuation of audio frequencies without introducing distortion is usually accomplished with pads. The graph shown above gives resistance value of the branches of an "H" or "T" pad for channels having an impedance of 200 or 500 ohms. The range of attenuation is from 2 to 32 db.

The text of this lesson was compiled and edited by the following members of the staff:

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UNIT NO. 4

SPEECH INPUT EQUIPMENT

LESSON NO. 4

THE ROSETTA STONE

.....it unlocked secrets of the past.

For many centuries men sought to find the secret of Egyptian 'picture writing'. They knew that if a key could be found to the strange language of the tombs, the mists of the ages would roll back to reveal the long forgotten history of Ancient Egypt....the misery of the slaves, the pomp and ceremony of the Pharaohs. Biblical stories would be proven....legends and stories of earliest civilization, thrilling tales of the ancients in the years of Rameses and Cleopatra; and Isis and Ra and Osiris.

But Egypt remained shrouded in mystery, and the history of the Nile, the Pyramids, remained untold.

And then in the year 1799, a workman who was digging near the ancient city of Rosetta unearthed a flat slab of rock-like basalt. Upon its crusted surface could be seen more of the strange writing of the ancient scribes, but----there also appeared the same sentences translated into a familiar language....Greek!

It was a ray of sunlight through a black corridor. Soon the scientists knew, after centuries of seeking, that this black stone held the secrets of the ages....the key to Ancient Egypt!

That remarkable historical discovery has since been called the Rosetta Stone. It is enshrined in a great museum, honored by thousands of visitors from every nation.

Just as the Rosetta Stone unlocked the secrets of Egypt to the scientists, so are your Midland lessons unlocking the secrets of Radio to you. The mysteries and amazing action of this modern science, Radio, are unfolding before your very eyes....you have already learned things you never knew before, and with each study - hour you are learning more absorbing facts and interesting, practical possibilities.

THINK OF THIS LESSON, AND EVERY OTHER LESSON, AS YOUR PERSONAL 'ROSETTA STONE'!

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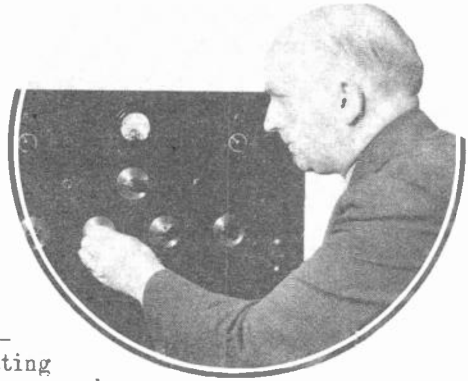
Lesson Four

SPEECH INPUT EQUIPMENT



"Control room operation is one of the most interesting phases of broadcast station work. A good control room engineer is an invaluable asset to the engineering personnel of any broadcasting station; his ability, attentiveness, and ingenuity are more responsible for the production of an excellent radio program than any other single factor. He may "make" or "break" a program.

"A control room engineer's ability depends largely upon his knowledge of the equipment and circuits with which he is working. In this lesson, I shall give a quantity of general information, then describe actual equipment with which you will be working in the broadcast field. Study these equipments--acquire a good knowledge of the commercial apparatus--every prospective employer is impressed by the man who can "talk commercially".

SPEECH INPUT EQUIPMENT

1. INTRODUCTION. Speech input equipment includes the studio microphones, control room amplifiers, and all of the miscellaneous jacks, switches, meters, attenuators, etc., essential for the efficient production of a radio program. The control room operator is responsible for the manipulation of all the controlling devices in order that the series of daily programs may be fed to the transmitter without unnecessary delay and at the proper db level. To unerringly fill his position, the control room operator must be intimately familiar with all microphones, amplifiers, and control devices entrusted to his care. All radio broadcast stations set aside a separate room called the "control room", wherein the operator performs his duties. The control room of radio station KMBC is shown in Fig. 1.

A simplified block diagram showing the essential components of a speech input installation is illustrated in Fig. 2, The weak audio frequency signals produced in the output of the microphone are first fed through a fixed gain amplifier known as the "preliminary amplifier" (pre-amplifier).[1] Fig. 2 shows two studio microphones, each connected to its respective pre-amplifier. The remote line indicates that provision is made for the broadcasting of a program originating at some location away from the main studios, the inter-connection being made with a telephone line. The fourth input provided on the simplified layout connects to the turntables, which are used for the creation of a program by means of phonograph records or transcriptions.

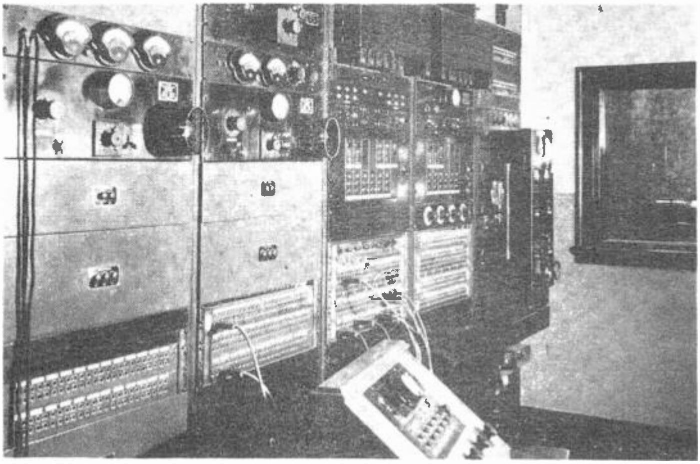


Fig.1 Control room of station KMBC.

Each of the four program sources is fed to a separate input position of the "mixer". The four units in the mixer consist of variable attenuators (volume controls). By carefully regulating the attenuators, the operator may properly control the volume level produced at the mixer output, or to main amplifier input. Any one of the four program sources may be fed into the main amplifier individually, or a "mixture" of two or more sources may be effected. The main amplifier is for the purpose of amplifying the program signal until it is of sufficient intensity to be delivered into the modulating system of the transmitter or into a telephone line connecting to the transmitter location. A volume indicator and a monitor amplifier are bridged across the main amplifier output so as to enable the operator to visually and aurally ascertain the level and quality of the program being broadcast. As indicated in Fig. 2, the same monitor amplifier supplies audio power to several other loud speakers located in the studios and offices of the broadcast station.

[1] The system of mixing wherein the microphone outputs are combined after pre-amplification is known as "high-level" mixing. This system is in contrast to the older method of "low-level" mixing, wherein the microphone outputs are combined before pre-amplification. Modern, high quality microphones have such a low db output that high-level mixing is much more satisfactory.

This elementary treatise of a typical speech-input installation acquaints the student with the sequence of the audio frequency amplification in a broadcast station control room. The principal job of the operator is to make certain that the proper microphone, remote program, or turntable is fed through the amplifying circuit at the correct time; also that the volume level of the A.F. energy into the transmitter is maintained accurately. To facilitate the

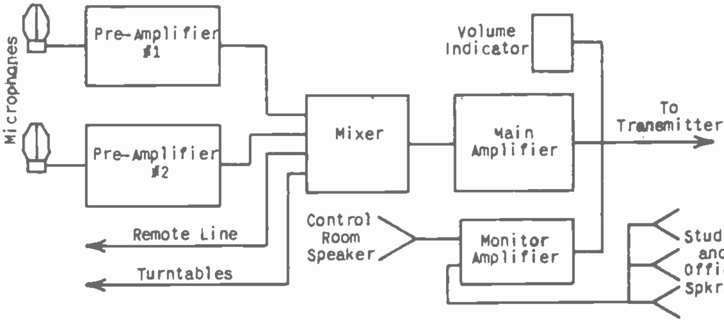


Fig.2 Illustrating the essential components of a speech input installation.

ease with which he may change to various program sources, the operator is provided with numerous switches, jacks, and volume controls. These, in addition to testing instruments, protective devices in case of error, etc., constitute the equipment generally found in the control room of a broadcast station.

The major part of the operator's time is spent at the controls on the mixer panel. He manually controls the gain of the amplifying system, bringing up the level of the softer passages in the program, and decreasing that of the louder passages to prevent overloading. By so doing, the average percentage of modulation on the carrier wave is maintained at a high level.

It should be pointed out that when the "gain" of the amplifying system is increased and decreased by the operator, it is impossible to faithfully reproduce a musical program. For instance, during the rendition of symphony music, an actual volume range between the loudest and softest passages of 60 db may be covered by the musicians. Through the control operator's efforts to maintain high modulation on the carrier wave, this range will probably be compressed to around 30 to 40 db. Unfaithful transmission of the program is certain to result; however, it generally passes unnoticed by the average layman. An operator may completely ruin an otherwise perfect program by "overriding" the gain control on programs of this type. On the other hand, he must be alert so as not to permit excessive peaks to pass through the system, which are apt to damage the transmitting equipment. It is thus realized that the job of the operator ("riding gain", as it is called) is no simple one if he is to discharge his duties in the most efficient manner. Experience, a strong desire to do his best, and a technical knowledge of the apparatus with which he is working are the primary requisites of a good control room operator.

2. COMPONENTS OF A SPEECH INPUT SYSTEM. In this discussion, we shall endeavor to give more complete and definite information on the general purpose and design of each of the components in a speech input system.

(A) Microphones. Since the microphone is the unit which converts sound energy into audio frequency electrical energy, it should be included as a portion of the speech input system. However, Lesson 2 of this unit dealt with the construction and operation of broadcast microphones to the extent that no more discussion should be necessary.

(B) Pre-amplifiers. The audio frequency energy generated by the microphone in the studio is delivered into the control room through well-shielded cables especially designed for the purpose. Since the audio signal is of minute magnitude, it is extremely essential that all precautions be taken in order to prevent cross-talk into the microphone lines or the development of erratic line noises.

This includes not only thorough shielding of the cables, but also the plugs and sockets at the cable ends are of importance. Their construction must be such as to insure absolute and firm contact at all times; even the slightest variation in contact resistance will produce serious noises in the circuit.

From the termination board in the control room, the A.F. from the microphone is fed to the input of a pre-amplifier. The pre-amplifier is generally of the fixed gain type, having one or two stages of vacuum tube amplification. Ordinarily, the db gain of the unit is from 40 to 60 db. Since the pre-amplifier is required to amplify audio signals of such low magnitude, it is essential that all amplifier noises such as hum, tube noise, and general circuit noise caused by thermal agitation, be kept extremely low. The tubes selected for use in the pre-amplifier must be especially quiet in operation. They must be non-microphonic,[1] and in some cases, must be mounted in cushioned sockets to protect them from mechanical and acoustical shocks. The tube sockets should be constructed so as to permit the tube prongs to "wipe" the contact arms, insuring a clean, firm connection between the two. The transformers used in a pre-amplifier must be free from core lamination vibration. Stray AC fields are very apt to induce a hum voltage in the windings; hence the number of turns on the primary and secondary is generally kept low. The inductance is kept high by high permeability core materials. Individual shields of heavy permalloy or soft iron are employed to enclose each unit.

In order to prevent the loss of signal energy, the output of the studio microphone should be properly matched to the input impedance of the amplifier, then the output of the pre-amplifier correctly matched to the input of the attenuator or amplifier to which it is connected.

In most broadcast installations, at least three pre-amplifiers are employed in each control room, each normally connected to the output of a studio or an announcer's microphone. To make these

[1] Refer to Lesson 8, Unit 2, Section 15.

same pre-amplifiers available for other purposes, quite frequently the input circuit is arranged so that other microphones, not having a separate pre-amplifier, may be conveniently connected to the input through a key switch or plug-jack arrangement.

Pre-amplifiers are generally constructed on regulation size 19" steel panels which fit into the standard racks employed in most control rooms for the assembly of their speech input equipment.

(C) Mixer. The mixer panel in a speech input installation may consist of three to five constant-impedance variable attenuators to introduce a loss in the signal energy of from approximately 10 db to infinity. The 10 db is the "insertion loss" resulting from the placement of the mixer circuit (as a unit) in the A.F. amplifying system. It represents the loss that will normally exist when the attenuator control is set for zero attenuation (maximum output).

All mixers fall into one of two classes, those having the attenuator units connected in series and those having the units in parallel. In order to maintain the constant input and output impedances necessary to prevent the loss of A.F. energy at all frequencies to be amplified, the variable attenuator controls are designed along the lines of the T, H, and ladder type pads as described in the preceding lesson.

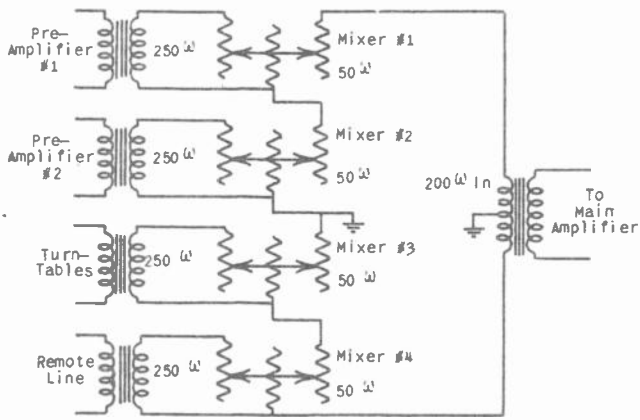


Fig.3 Four variable T pads in a mixing circuit.

An illustration of four variable T pads being used as mixers is shown in Fig. 3. Here two pre-amplifiers are employed, each connected to a respective microphone. The output transformer of each pre-amplifier has an impedance of 250 ohms. The record and transcription turntables are connected to the third mixer position; the fourth being occupied by the output of a remote program line. Each of the transformer secondaries has 250 ohms impedance and must be terminated into a 250 ohm load. By selecting the proper resistance values for the series and shunt arms of the T type attenuator, the input impedance can be made equal to 250 ohms at all settings of the control. Each of the mixers shown in Fig. 3 has exactly the same input impedance (250 ohms) and each is being fed from a 250 ohm transformer secondary. The output impedance of each mixer is 50 ohms. The output impedance is also kept constant at all settings by the compensating changes in the series and shunt arms. All four of the mixers are connected in series across the primary of the input transformer to the main amplifier. Since each mixer has an output impedance of 50 ohms, the total of the series combination will be 200 ohms, thus the four mixer units are shown working into a 200 ohm primary impedance of the main amplifier. The center of the primary winding is grounded, and also the center of the four series mixers. The latter ground connection is shown between mixers 2 and 3. The purpose of grounding the mid-points on both sides of this circuit is to eliminate induced hum and static circuit noises from being fed to the input of the main amplifier. Being balanced to ground in this manner, any hum or noise currents produced in the wires leading from the mixer to the input of the main amplifier will pass through the primary of the output transformer in opposite directions, thus developing out of phase fields around the two halves of the primary winding which cancel each other.

Ladder-type attenuator pads are used in most broadcast installations. They make exceptionally fine controls when used in either series or parallel mixer circuits. A balanced H ladder attenuator circuit, as used in the RCA 46A mixer panel, is shown in Fig. 4A. The output circuits of each mixer are combined into a transformer having a secondary tapped at 250 and 500 ohms. A rear view of the four position mixer panel is shown in Fig. 4B. Each mixer is provided with 20 contacts, and 2 db attenuation is produced between steps. The first contacts short the input so that infinite attenuation is produced and any disturbance in the channel will not be introduced into the common output. Each mixer unit is provided with a shield which also prevents dust from entering.

The output of each microphone in a broadcasting station is usually not permanently connected to the input of a pre-amplifier. There are generally from three to five pre-amplifiers used, depending on the size of the station. As the microphones distributed throughout the various studios are to be used for program origination, they are connected into the pre-amplifiers by means of simple switching arrangements. Also, if several remote lines are employed, the one to be used may be switched individually to a position on the mixer panel. Thus the operator can properly regulate the level of a program coming over any of the many remote lines by using the position on his mixer panel designated for that purpose. The same would be true for several turntables located in different parts of the station, such as in the control room, transcription room, or studios. Adequate switching facilities will be discussed later.

(D) Line Amplifiers. Line, main, and program amplifiers are various names used to designate the same piece of equipment in a broadcast station. The program to be broadcast is fed through the amplifier, then into the transmitter proper or into a telephone line connecting to the transmitter. Its purpose is to raise the

program level from the output of the mixer to 0 db, which requires about three stages of high quality amplification. Particular care must be taken to make certain that no harmonic or frequency distortion is introduced and that all tube and circuit noises are minimized. Since the program amplifier is amplifying audio frequency at a much higher level than the pre-amplifier, it is not essential to exercise such extreme care in its mechanical construction. However, sufficient precaution must be taken to insure that the average hum and noise level is at least 70 db below the program level.

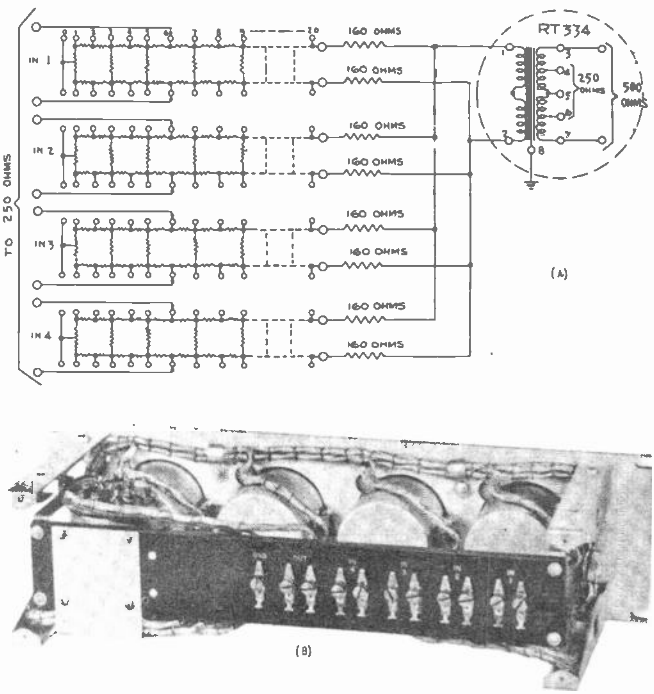


Fig. 4 (A) Schematic diagram of RCA 46A mixer panel. (B) Rear view of RCA 46A mixer panel.

The gain of the pre-amplifier, the setting of the attenuator in the mixer, and the gain of the program amplifier should all be set so that the loudest passages in the program to be broadcast will produce an output of 0 db from the program amplifier. This means that a gain of about 70 db must result in the equipment up to this point. The main reason for limiting the program amplifier output to 0 db is that in most instances it is used to feed a telephone line connecting to the transmitter. To avoid serious "cross talk"; that is, leakage from one line to another in their cables, the telephone company limits the normal program level to 0 db (.006 watts) and its peak at any instant to +2 db. Of course, if no telephone line is necessary to the transmitter, the program amplifier output level may be set to any convenient value. This would be the case in smaller stations with the transmitter located in the control room.

The output impedance of most program amplifiers is 500 or 600 ohms. A volume indicator and monitor amplifier (one or more) are always bridged across the low impedance output terminals. Most speech input installations include two program amplifiers, one to be used for the daily broadcasting and the other for audition and "stand - by" purposes. Duplicate equipment is quite important to prevent the loss of time on the air, and it is equally true that

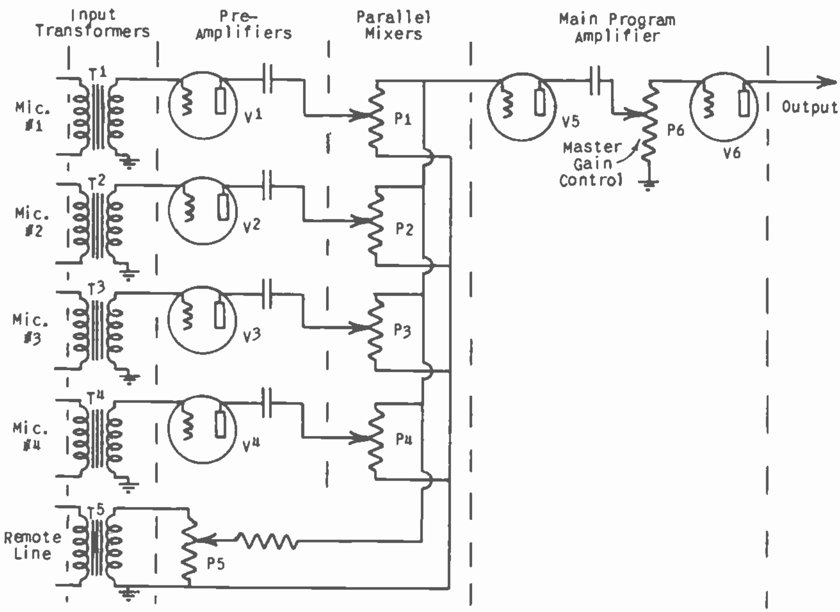


Fig.5 Simplified electronic mixing circuit as used in W.E. 23A Speech Input Equipment.

auditions must be given regularly at broadcast stations to provide new talent and to sell programs to prospective advertisers. A second main program amplifier in the speech equipment suffices for both these purposes.

(E) Electronic Mixing. In several of the later equipments available, the microphone mixing is performed "electronically"; that is, the output of each pre-amplifier is terminated into a simple potentiometer, then these potentiometers are parallel across the input to the first amplifying tube in the program amplifier. A simplified schematic of the Western Electric 23 - A speech input equipment is shown in Fig. 5 to illustrate "electronic" mixing. Four microphone channels are provided, each coupled through an

impedance matching transformer to the grid of a single stage pre-amplifier. The fifth input to the mixing circuit is through a matching transformer from remote program lines. The potentiometers P1 to P5 are all connected in parallel; P1 controls the output of V1 to the grid of V5; P2 controls the output of V2 to the grid of V5; etc. If a microphone is not to be used, its respective potentiometer on the mixer panel is closed by moving the arm to the bottom. Opening any one or more of the potentiometers feeds the A.F. signal from that source into the main program amplifier. Fading from one circuit to another is easily accomplished and any number of the microphones (or remote lines) may be used simultaneously. V5 and V6 constitute the main program amplifier and P6 is used as the main gain control.

The simplicity and economy of "electronic" mixing are largely responsible for its popular use in present day equipment. The minimum of parts required permits the manufacturer to house a complete speech input system in a small console which can be placed on top of the operator's desk. The Western Electric 23-A speech input system will be described with more detail in a later portion of the lesson.

(F) Volume Indicators. The inability of the ear to judge variations in sound intensity accurately makes it necessary to provide a meter across the output of the program amplifier for the purpose of visually monitoring the program. The device used for

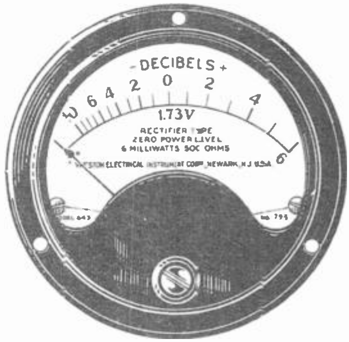


Fig.6 Photograph of V.I. meter.

visual monitoring is known as a volume indicator (abbreviated V.I.) and may consist of a high impedance copper oxide voltmeter or a vacuum-tube voltmeter. Instead of being calibrated in volts, the V.I. meter has its scale marked in decibels, generally with 0 at the center. The left side of the instrument scale is then calibrated in negative decibels (below zero) and the right side in positive decibels (above zero). A single instrument may be used to read several decibel ranges other than in the vicinity of zero level as will be explained in the next paragraph. Fig. 6 shows the scale of a V.I. meter. To be satisfactory, the action of the meter movement should be fast enough to fluctuate with the variations of audio level in the program.

A in Fig. 7 shows a simplified schematic of the Western Electric 203-B V.I. panel which was so popular in older installations. The vacuum tube is biased nearly to cut-off by the drop across the filament resistor, adjustable with R. The tube then works similar to the operation of a grid bias detector, reproducing only the positive alternations of the grid signal in the plate circuit. With no signal, the bias is adjusted so that the needle of the plate current meter reads about .1 of full scale deflection, this being advisable to prevent the needle from striking the pin on the left side during the pauses in speech and music. The application of a varying grid signal then causes the plate current meter to fluctuate at a corresponding rate so as to indicate visually the average level

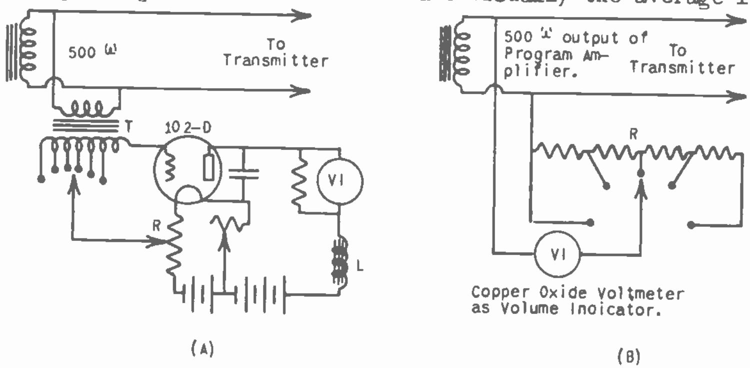


Fig.7 (A) Simplified schematic of W.E. 203B V.I. Panel. (B) V.I. meter using copper oxide rectifier and multiplier resistors.

of the voltages developed across the output of the program amplifier. The inductance L in the plate circuit serves to provide a plate load; this makes the rectification (positive alternation amplification) essentially linear and also makes the meter needle fluctuations follow the average program level. The primary of the transformer T is bridged across the 500-ohm program line; however, its impedance is so high (approximately 25,000 ohms) that negligible power is consumed. The secondary is tapped so that the V.I. may be made to read different input levels; the position of the arm making connection with the secondary taps is marked in decibels. The actual value in db of the program level is then the sum of the arm and meter readings. For example, if the arm is set to 0 db and the meter is reading +2 db, the program level is +2 db; likewise, if the arm is set to +8 db and the meter reading is -4, the program level is +4 db, etc. The V.I. meter itself generally requires about 1 to 1½ ma. of DC current for full scale deflection.

A copper-oxide rectifying type V.I. meter is shown at B in Fig. 7. This type of V.I. meter has the advantages of lower cost, no power supply, simplicity, and it occupies less space. Its use is now common among the manufacturers of speech input equipment, being made practical since the development of copper-oxide rectifiers that were free from frequency discrimination up to about 15,000 cycles. A DC meter having a sensitivity of about 5,000 ohms per volt is used in conjunction with the rectifier so as to indicate the fluctuations of the audio voltages across the output of the program amplifier. The tapped resistor R provides for changing the scale of the V.I. in order that it may read different audio levels. The position of the selector switch on the tapped resistor is calibrated in decibels (as is the scale of the meter); hence, the instantaneous program level is the sum of the switch and meter readings, the same as described with the tube type V.I. meter. When the switch and meter are both reading 0 db, the A.F. voltage across the 500 ohm line should have an R.M.S. value of 1.73 volts. The high value of the series multiplier resistor makes it possible to bridge the rectifier type V.I. directly across the low impedance program line without effecting a loss of audio power. The meter itself is generally of the 3-inch scale size and is permanently built into the front panel of the program amplifier. In some amplifiers, the scale is indirectly illuminated with a pilot lamp.

The speed of fluctuation on a V.I. meter is mostly a function of the design of the movement. They may be obtained with a "slow", "fast" or "general purpose" characteristic. The choice ordinarily is one of preference; however, if different speed V.I. meters are bridged across the same audio line, they cannot be expected to indicate the same value on program peaks. This may be rather confusing during network shows or on remote control programs. An attempt should be made to standardize all of the V.I. meters used in a broadcast station even if they can't be made to conform with the network equipment.

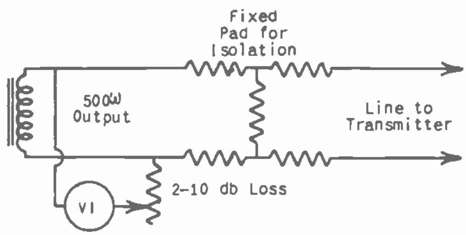


Fig.8 Illustrating connection of V.I. meter on output of line amplifier.

For the calibration of a copper oxide V.I. meter to be accurate, the impedance of the line across which it is connected must remain constant. When an instrument is designed for universal use across lines having different impedance values, correction curves are supplied to enable the user to determine accurately the audio power level. Even when across a 500 ohm program line, it should be understood that the line impedance does not remain constant at all frequencies. There is certain to be a decrease in line impedance at the higher audio frequencies due to the distributed capacity of the line. Thus, if exactly correct at 400 cycles, the calibration of the V.I. meter is apt to be considerably low at 10,000 cycles. To prevent this, a fixed pad is generally placed in the line, then the meter connected on the amplifier side to isolate line impedance changes from affecting the calibration. This is illustrated in Fig. 8. Whatever the loss in the fixed pad might be (usually from

2 to 10 db), a corresponding increase must be delivered from the program amplifier so as to continue feeding the telephone line at 0 db.

(G) Monitor Amplifiers. Aural as well as visual monitoring is essential for the operator to make certain that the program being broadcast is of a high quality nature. Aural monitoring is accomplished by providing a separate amplifier and a loud speaker which enables the operator to hear what is being broadcast at all times. He can also hear line noises, audio distortion, and other effects which might result in unpleasant reproduction at the radio receiver. These will not ordinarily be apparent on the volume indicator meter.

As well as enabling the operator to check the outgoing program, the monitor amplifier also drives several other speakers located in the studios, audition rooms, visitors gallery, and general offices. Thus, the entire personnel of the broadcasting station is continually aware of what is being broadcast—a condition that is essential for the maintenance of high quality programming.

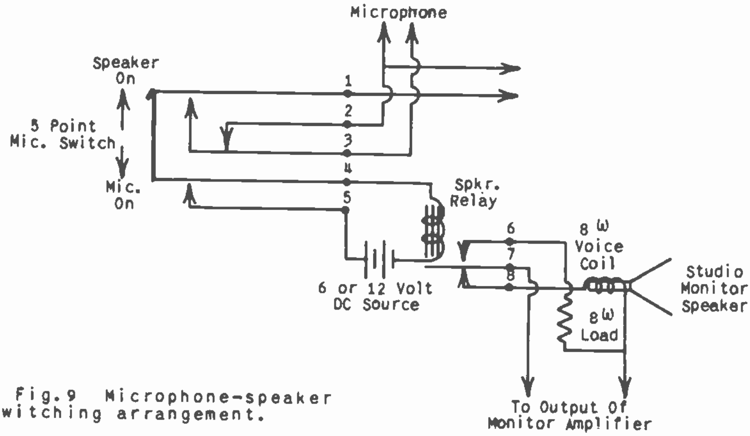


Fig. 9 Microphone-speaker switching arrangement.

In practically all speech-input installations, the input of the monitor amplifier is bridged directly across the output of the program amplifier; that is, across the line to the transmitter. To prevent the monitor from placing an excessive load on the program line and thereby upsetting the impedance relations in the line, its input impedance must be quite high. An input impedance of 4,000 to 20,000 ohms is common for most monitor amplifiers.

With the output of the program amplifier controlled to about 0 db, the input level to the monitor amplifier will be the same. The monitor will consist of from two to four stages of A.F. amplification, the final stage being a power amplifier capable of delivering the audio power necessary to drive all of the monitor speakers. Whereas, the control room and office speakers are in operation continually, the studio speakers must be cut off when a program is to originate in that studio. This is generally accomplished by the switches controlling the microphones in that studio; that is, when a microphone is switched on, the studio monitor speaker is simultaneously cut off by additional contacts on the microphone switch which operates a speaker relay. The speaker relay must also place a resistor of the proper value across the monitor line where the speaker was formerly connected in order that the load impedance on the monitor amplifier will not change. Such a microphone-speaker switching arrangement is illustrated in Fig. 9. Five points are used on the key switch, 2 and 3 connect to the microphone, 1 and 2 to the input of the pre-amplifier, and 4 and 5 to the speaker relay circuit. The microphone key switch is shown in the "speaker on" position. The microphone output is now shorted across contacts 2 and 3. The open connection between 4 and 5 will not permit a DC current to flow from the six (or twelve) volt battery through the speaker relay

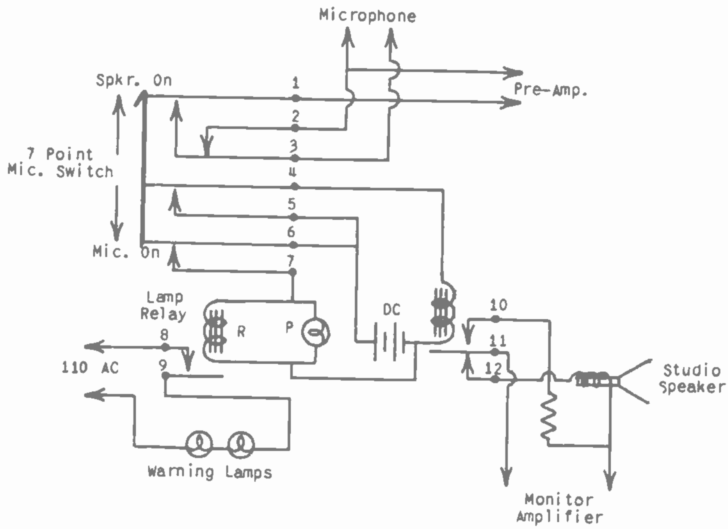


Fig.10 Microphone switch with warning lamp relay circuit.

coil. Thus, the armature bar 7 will remain in contact with point 8 and the output of the monitor amplifier will be delivered directly into the voice coil of the studio monitor speaker. When the microphone switch is thrown to the "microphone on" position, the short is relieved between 2 and 3 as 1 pushes downward on 3. The contact made between 1 and 3 connects the output of the microphone into the pre-amplifier. At the same time, connection is made between 4 and 5 which closes the speaker relay circuit. As the DC current passes through the relay coil, the magnetic field attracts the armature bar 7. Upon moving upward, 7 breaks contact with 8 to open the voice coil circuit and makes contact with 6 to connect the 8 ohm resistor across the monitor output in place of the voice coil.

Fig. 10 shows the same microphone-speaker switch as in Fig. 9

except that two additional points have been added which, together with a relay, illuminate a "program" pilot lamp on the control panel and turn on a warning lamp over the studio door. The pilot lamp and relay also operate from the external DC source. When in the "speaker on" position, no connection is made between points 6 and 7. When the key switch is thrown down to the "microphone on" position, the DC circuit is completed through the lamp relay. The DC current divides, part passing through the pilot lamp P on the control panel and part passing through the relay coil R. Current through the relay coil closes points 8 and 9, which in turn complete the 110 volt AC circuit to illuminate the warning lights over the studio door. Most stations have a large sign "STUDIO IN USE" outside the studio to prevent program interruptions when the microphone in that studio is being used.

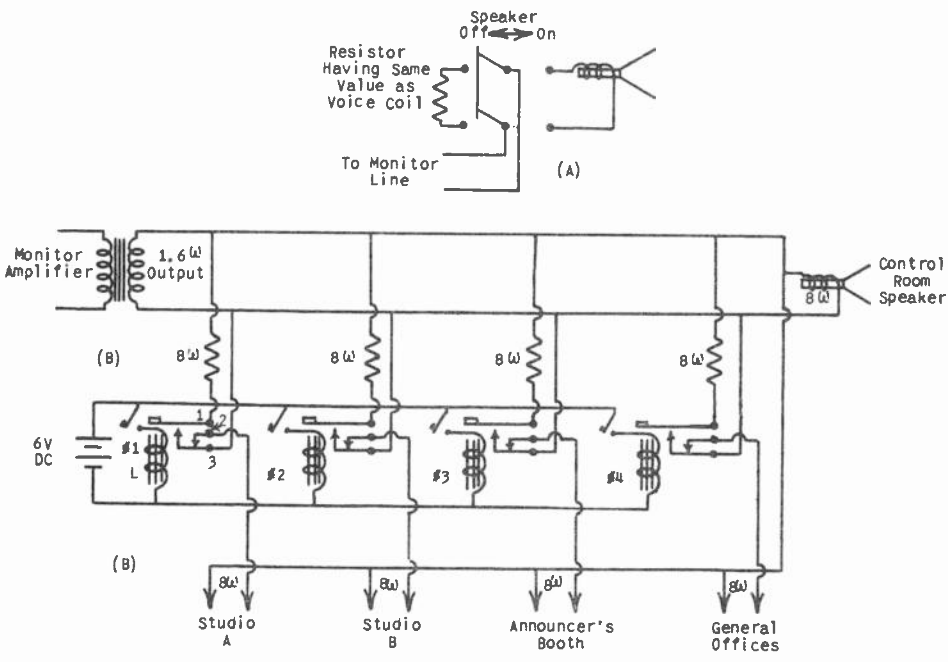


Fig. 11 (A) Double-pole double-throw switch for monitor speaker switching. (B) Relay circuits for switching monitor speakers.

The monitor amplifier is used to drive several speakers; however, at times it may be desired to turn one or more of these speakers off. If the voice coil circuit to the speaker is merely opened, a mismatch of the secondary impedance on the monitor amplifier results, affecting the volume from the other speakers on the line and probably producing considerable distortion. A double pole double throw toggle switch may be employed to throw a fixed resistor across the line when the speaker is removed (shown at A in Fig. 11) or a relay system may be incorporated to execute the change. A relay system is often found more convenient because it permits a remote control of the switch. Such a system designed for four speakers is shown at B in Fig. 11. A six volt DC source is used to operate the relays 1, 2, 3, and 4. The control room speaker is permanently connected. Explaining relay 1 (the others are the same), when the toggle switch is in the open position, one side of the monitor line is connected to one side of studio A speaker line through points 2 and 3. The other side of the monitor line is permanently connected, so the speaker is in use. When it is desired to cut off the speaker in studio A from the monitor line, the switch to coil L is closed. The field around L attracts armature 1; as it moves down it makes contact with 3, pushing it down and opening the connection between 2 and 3. At the same time the 8 ohm load resistor is placed across the monitor line to take the place of the voice coil. The other four relays operate in the same manner. By using a relay switch which has more points, it is also possible to illuminate a pilot lamp the same as in Fig. 10 to indicate that the speaker is either on or off the line.

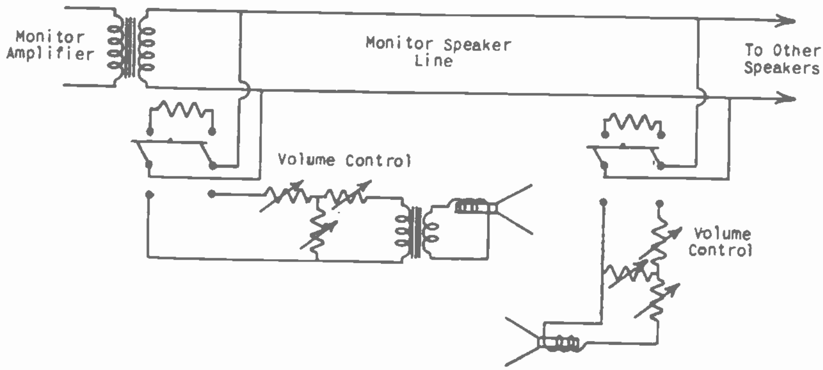


Fig.12 Using variable T pads for individual volume controls on monitor speakers.

In the preceding examples, the main gain control on the monitor amplifier will determine the volume of all of the monitor speakers. This is often undesirable due to the varying noise conditions in the studios and offices. A method of placing an individual volume control on each of the speakers is shown in Fig. 12. If the speaker is on, the DPDT switch is in the down position, if off, the switch is up to place the dummy load resistor across the secondary. Assuming the switch is down, the input impedance of the variable T pad must be the same as the value of the load resistor. It is assumed that the output transformer secondary impedance is properly matched by all of the speakers paralleled across the line. The output impedance of the variable T pad may match the primary of a step down transformer into the voice coil of the speaker (shown on the left) or it may directly match the voice coil impedance (shown on the right). In either case, the T pad should maintain a constant input and output impedance at all settings, thus controlling the speaker volume without changing the load on the output of the monitor amplifier.

Each monitor speaker is sometimes supplied with an individual amplifier. The inputs to the several amplifiers would then be bridged across the main program line. Whereas this method is more satisfactory from the standpoint of individual volume control and isolation of the separate speakers, its greater expense prohibits its general use.

(H) Jack strips. Jack strips are used as termination boards in a speech input installation. On these strips (see Fig. 15 for illustration), the input and output terminals of practically every piece of equipment in the speech input installation are terminated at small jacks. The standard jack strip contains 24 jacks (12 pair) mounted horizontally in a row; the assembly is of standard length so as to mount in a 19" rack. Often, two rows of jacks (24 in each row) are mounted on a 19" panel about 3½" inches wide. The purpose

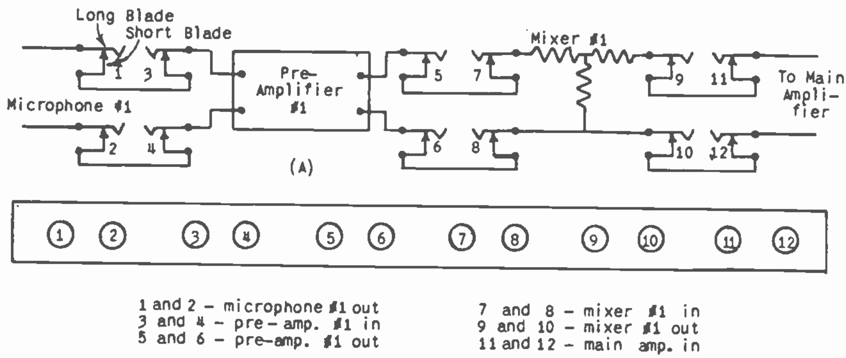


Fig. 13 (A) Showing wiring connections through jacks on jack panel. (B) Front view of jack strip.

of terminating the input and output of each piece of equipment in the control room on a jack strip is to make the overall installation flexible to the extent that the operator may easily and quickly change the channel of a program without interruption. In case of apparatus failure, he may reroute the program so quickly that only a very few seconds will be lost on the air; he may use part of the equipment for auditions, part for the main program, part for monitoring new records or transcriptions, etc., all at the same time. The importance of such flexibility and convenience cannot be disregarded in a modern control room installation.

To illustrate the primary purpose of a jack strip, let us refer to A in Fig. 13. The two sides of the microphone line are connected to the long blades of jacks 1 and 2, then the short blades on these jacks are in turn connected to the short blades on jacks 3 and 4.[1] Jacks 1 and 2 would be labeled "microphone #1 out" on the jack strip, and 3 and 4 would be labeled "pre-amplifier #1 in". The reason for these designations may be explained as follows: The

[1] This is called a "normal through" connection.

front of the jack strip would appear on the control panel as a series of holes such as shown at B in Fig. 13. A "patch" cord for insertion in these holes is shown in Fig. 14. A patch cord consists of a two-wire flexible cable, from 12 to 48 inches in length, having a two-prong plug on each end. The two plugs are identical in size and construction. Each prong on the plug has two sections, a tip and a sleeve, insulated from each other by a small bakelite washer. A flexible lead is connected to the tips of the prongs, as shown by the dotted lines in Fig. 14. The spacing between the prongs on

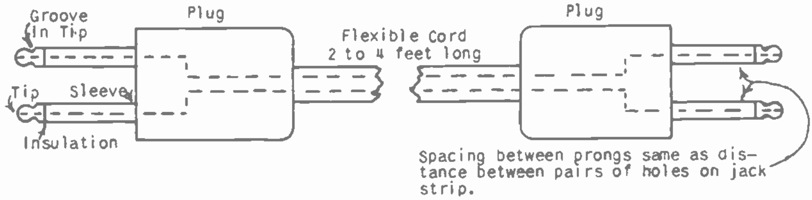


Fig. 14 Illustrating the internal wiring of a patch cord.

the plug is exactly the same as the distance between a pair of jacks on the jack strip. Now, when one of the plugs on the patch cord is inserted into jacks 1 and 2, the connection between the short and long blades on the jacks is opened, because the tips of the prongs push the long blades up. The tips of the prongs "lock" into positive contact with the long jack blades as the projections at the ends of these blades fall into the recessed grooves behind the tip heads. The output of the microphone is then disconnected from the input to pre-amplifier #1 and is brought to the tips of the prongs on the other end of the patch cord. Hence, the reason for the label "microphone #1 out". Microphone #1 is brought "out" on the patch cord to the tips of the plug at the opposite end. Now, if it is desired to feed the microphone directly into mixer #1; that is, bridge or "patch" around the pre-amplifier, insert the plug at the opposite end of the patch cord into jacks 7 and 8. These are labeled "mixer #1 in". Upon inserting the plug into jacks 7 and 8, the long blades make contact with the tips on the prongs of the plug, and at the same time the short blades are disconnected from the long blades to remove the normal connection from the output of the pre-amplifier.

By these foregoing operations, both the input and output of pre-amplifier #1 was opened; the amplifier can now be used to amplify the output of some other microphone if desired. A patch cord would be used from the "microphone out" position on the jack strip (not shown at B in Fig. 13) to the "pre-amplifier #1 in" position. The output of pre-amp. #1 would then have to be patched into some other mixer besides mixer #1.

As the wired arrangement stands at A in Fig. 13, the microphone #1 is said to be "normal through" to the input of the main amplifier. This means that without the use or insertion of any patch cords, microphone #1 will "normally" pass into pre-amplifier #1, through mixer #1, and into the main amplifier. If a patch cord plug is inserted into any pair of jacks along the circuit, the "normal through" condition is destroyed.

When arranging the layout of a complete jack panel, it is important to use care in the selection of the positions for the various terminations. Most important of all, the low level and high level positions must be widely separated to prevent cross-talk between the numerous incoming lines. A "low level" position means the termination for the input or output of a piece of apparatus wherein the level of the audio energy is extremely low, say -50 to -100 db. A "mic. out" position and a "pre-amp. in" position are both examples of low level. A "high level" position on a jack panel means the termination of a piece of equipment wherein the level of the audio energy is high, such as the "main amp. out" or "monitor amp. in" positions. The output of a pre-amplifier, phonograph pickup, or remote line may be considered "medium level". Actually, the input to a remote line is always 0 db, but upon traversing the telephone line to the studio, a loss occurs which makes the level at the termination board (jack strip) in the control room less than 0 db. Then, too, a remote line is nearly always patched directly into a 10 or 20 db pad, and an equalizer is placed across the line. The object of feeding the remote line through a pad is to isolate the line from the control room equipment and, at the same time, bring the level of the remote program down to where it can be passed through the mixer panel and main program amplifier.

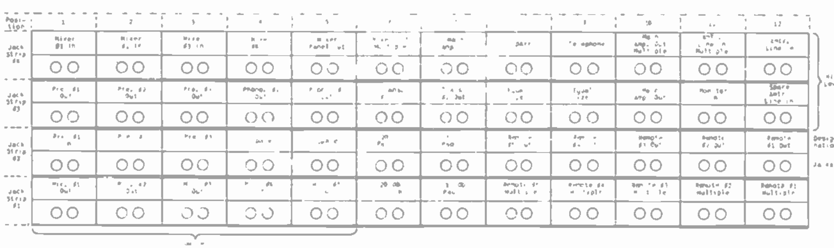


Fig. 15 Typical jack panel layout in medium size broadcast station.

To illustrate how a jack panel might be laid out, let us refer to Fig. 15. Four strips are used on this panel, with a designation tab above each of the positions. First, the outputs of five microphones are connected to jacks in the lower left corner. The "pre-amp. in" positions are located directly above each of the first three microphone "outs". Only three pre-amplifiers are used in this installation. Progressing on up to jack strip #3, the "pre-amp. out" positions are next, then the "mixer in" positions. Mic. #1 is normal through pre-amp. #1 to mixer #1, mic #2 is normal through pre-amp. #2 to mixer #2, and mic. #3 is the same into mixer #3. Each of these normal through circuits passes upward on the jack panel as the level increases. This keeps the signal level in wires or cables leading to neighboring jacks behind the panel at approximately the same level. The cables always run behind each jack strip horizontally, thus, the five microphone cables coming to positions 1, 2, 3, 4, and 5 on strip #1 would be close together, the three pre-amplifier output leads on strip #3 would be close together, etc. Even though two or three of these leads might be carrying a signal at the same time, there will be no cross-talk because the level in each is the same. However, this fact does not prevent the necessity of properly shielding these leads. The remote lines (with their multiples) are placed on the lower right of the panel. All of these lines will be laced into one cable as they are brought from the telephone company's terminal board to the jack panel. The lines will be taken out of the cable, a pair at a time as the cable passes along behind the panel, then soldered to the proper jacks. All of the high level terminations are near the upper right of the panel, far away from the low level microphone inputs.

Whereas the complete jack panel layout in each broadcast station is different due to the different equipment employed and different flexibility requirements, it will be found that invariably the terminations for the low level equipment are kept as far as possible from the high level terminations. The jack panel layout in Fig. 15 also shows positions for pads, equalizers, transcription tables, a control room telephone, transmitter (xmtr.) line, and spares for future additions to the equipment. "Mul." is an abbreviation for multiple, meaning a parallel jack outlet.

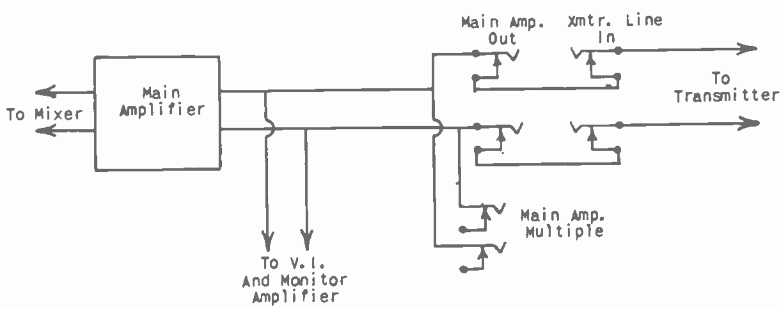


Fig.16 Illustrating "multiple" connection.

In the design of speech-input equipment for smaller stations, there is a tendency to eliminate the use of jack strips, employing key switches instead. Whereas this system is not nearly so flexible, it is generally sufficient for the operation of two studios.

It is advisable to provide outlets on the jack which are in parallel with the main program sources and lines. The operator frequently has an occasion to connect a pair of headphones across a remote line while a remote program is in progress, and quite often he finds it necessary to monitor the telephone line to the transmitter while a program is being broadcast over the line. Provisions should be made on the jack strip to accommodate these parallel connections when the occasions arise. A jack position in parallel with a line is called a "multiple". Fig. 16 shows a multiple on the output of a main program amplifier. Multiple or parallel jacks are essential for headphone monitoring or when it is desired to feed the program into an additional load. If a patch cord plug were inserted in the "main amplifier out" jack, the line to the transmitter would be broken and the program interrupted. With a multiple outlet; however, the line can be monitored without any effect on the program. High impedance phones (2000 ohms or above) must be used.

(I) Transcription equipment. The transcription equipment in a broadcast station consists of the turntables, driving motors, and pickup arms used to play records and transcriptions. All phonograph records are played with the record revolving at a speed of 78 r.p.m.; while transcriptions are generally run at 33⅓ r.p.m. Phonograph records and some transcriptions are cut "laterally", which means that the grooves cut by the recording needle are vibrating back and forth in accordance with the amplitude and frequency of the audio signals. On the other hand, transcription discs are generally cut "vertically", which means that the groove does not vibrate back and forth, but instead varies in depth. To reproduce the audio signal on a record or transcription, it is necessary to employ a reproducing head that is designed to develop the audio voltages when the needle is vibrated according to the type of cut on the disc. A lateral reproducing head will not respond to the depth variations of a vertical cut groove, nor can a lateral cut record be played with a vertical reproducing head. Thus, if the station's transcription equipment is to be complete, it must be capable of playing both vertical and lateral cut discs, revolving at either 33⅓ or 78 r.p.m.

(J) Remote Amplifiers. A microphone and amplifier are required at the remote point of broadcasting. This apparatus is similar to the studio equipment except that it is constructed in such a way as to achieve utmost portability and minimum weight. An amplifier must be provided to elevate the audio level from the output of the microphone to 0 db for feeding the telephone line connecting to the main control room at the broadcasting station. Sometimes two or more microphones must be used for the remote broadcast, so facilities for mixing must also be provided. A volume indicator, headphone monitor, and a power supply are also essential in the proper design of remote equipment. A loud speaker monitor cannot be used because of the amplifiers proximity to the microphone.

Remote amplifiers available from equipment manufacturers will be discussed later in this lesson.

(K) Speech Equipment at the Transmitter. When the transmitter is located away from the downtown studios and control room, a telephone line must be used to carry the program. The desirability of locating the transmitter outside the crowded metropolitan area lies mainly in the fact that a much greater area may be covered with a given antenna power and that the interference problems created when a number of high powered stations operate in the same small area is greatly reduced. Locating the antenna away from steel build-

ings, trees, power plants, etc. greatly increases the efficiency of radiation, making it possible for the radio station to reach a greater audience and enhancing its commercial income from sponsored programs. Undoubtedly this system means additional expense at the time of installation, but it has been proved to be the more satisfactory from the standpoint of year in and year out broadcasting.

It has been previously mentioned that the telephone company will not permit their lines to be fed at an average audio level higher than 0 db. After the signal traverses through 5 to 20 miles of cable, a considerable loss has incurred, so additional audio amplification is necessary at the transmitter. This amplification will compensate for line and equalizer losses so that the A.F. signal may be fed into the modulating system of the transmitter at the proper level. The speech amplifier at the transmitter is generally of the same design as the main program amplifier in the control room. Most commercial transmitters specify an audio input level to the modulating system of from 0 to plus 6 db; all program amplifiers are capable of elevating the signal level to this value without undue frequency or harmonic distortion.

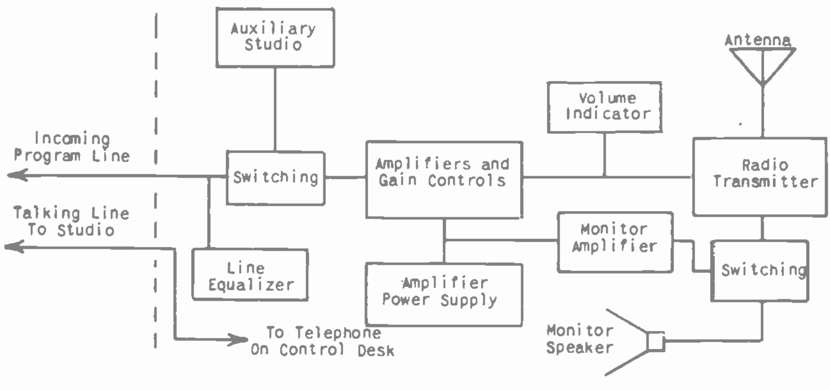


Fig. 17 Block diagram of equipment layout at transmitter plant.

Furthermore, it is necessary to provide loud speaker monitoring and a volume indicator as well as amplification controls, switching and means of emergency announcing at the transmitter location. Loud speaker monitoring of the input to the transmitter must be obtained from a separate monitor amplifier; however, the design of the transmitter itself generally provides for monitoring the output of the modulated stage. In case of trouble on the telephone line to the studio, the station would be off the air if it were not for provisions at the transmitter to maintain an emergency program consisting of recordings, transcriptions, and announcements. In some cases, an emergency studio is also built at the transmitter plant, so that if necessary, broadcasting can be carried on the same as at the studio. A block diagram of a transmitter plant layout is shown in Fig. 17.

3. REQUIREMENTS OF A SPEECH INPUT INSTALLATION. From the time that sound or acoustic energy is translated into electrical energy by the microphone, it is subject to a series of electrical operations, such as preliminary amplification, mixing or combining of outputs from several sources, switching, power amplification, transmission over telephone lines, equalization and reamplification. In all these operations, the frequencies and relative intensity of the original sound must be carefully retained in order that the ultimate result when reconverted into sound may be a faithful representation of the original sound. This requires electrical equipment of the best type capable of passing and amplifying without distortion a true electrical pattern of the original sound as created in the microphone. The introduction of extraneous sounds caused by faulty or imperfect switching, mixing, or gain control potentiometers, should be avoided. Also, the accumulation of noises from the amplifiers and the transmission lines must be carefully guarded against by the selection of high-power amplifiers with a low distortion factor and a negligible noise level.

There should be sufficient circuits and control flexibility to permit an interchange of amplifiers and control units from one channel to another in an emergency. Proper monitoring facilities should be provided to give a visual and an aural indication of the program output.

In order to improve the overall dependability of the equipment, and eliminate the trouble and expense of battery maintenance, the equipment should be entirely operated from AC lines. The question of power supply is an important one, especially in multi-channel systems, wherein a large number of amplifying and control units are involved. However, in the modern self-contained speech input equipment with AC power supply, separately fused at each equipment assembly, the question of power supply becomes relatively simple and additions to the speech input system which may be necessary to meet increasing service demands are greatly facilitated.

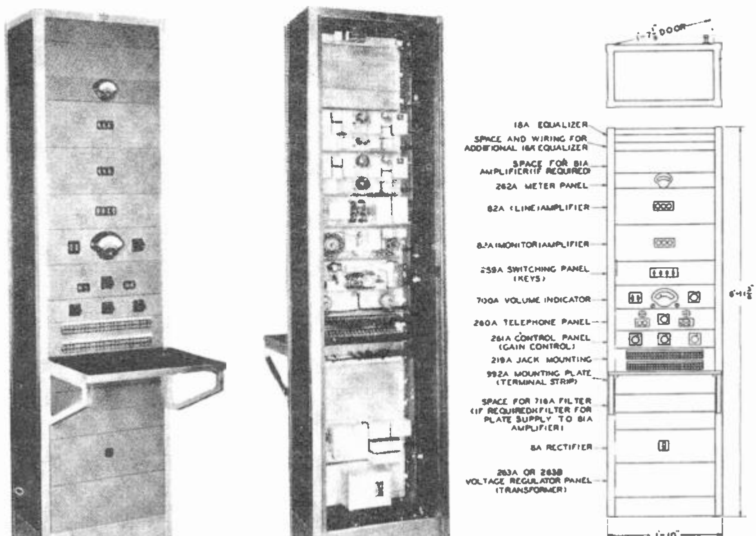
Aside from these electrical requirements, the equipment should be so designed mechanically that it may easily be operated and maintained. Unit assembly of the major apparatus components, such as amplifiers, volume indicators, mixing and gain control potentiometers, etc., wired and tested in the factory, result in low apparatus cost and low installation and maintenance cost. The employment of standard apparatus reduces engineering and system costs and facilitates the addition of new apparatus when required. The equipment should occupy a minimum floor space and be attractively designed so as to harmonize with its surroundings. Broadcast stations are show rooms. They serve to convince a customer of the station's ability to handle programs satisfactorily. Equipment should be substantial, up-to-date and attractive in appearance. It must create an impression of efficiency and dependability to the prospective purchaser of time on the air.

All of these aforementioned requirements should be taken into consideration when selecting a speech input system. In case the engineer decides to design and construct his own speech input equipment, all of these factors should likewise be taken into consideration, consistent with the economics involved.

The information given to this point in the lesson is of a general nature. Since the requirements of individual installations vary considerably, it is felt that a survey of the commercial equipment available will prove valuable to those interested in the purchase or knowledge of these equipments.

WESTERN ELECTRIC SPEECH INPUT EQUIPMENT

(4A) The 700A Speech Input Bay. A study of this complete speech input installation will afford a means of illustrating how the equipment in a modern control room would be arranged and also will give a comprehensive idea as to the amount of equipment that would be necessary.



(A) (B) (C)

Fig. 18.

A front and rear view of the 700A speech input equipment is shown at A and B in Fig. 18. The equipment consists of an assembly of the amplifiers, volume indicator, potentiometers, meter panels, jacks and other circuit accessories for one amplifier channel. This apparatus is assembled on a series of panels mounted in a steel cabinet completely wired and tested before leaving the factory. A block schematic of the equipment is shown in Fig. 19.

The 700A is designed to accommodate four incoming program circuits and two telephone lines. Due to the quietness of the program channels, noise is below the threshold of audibility when the gain is adjusted for normal operation.

Unequal transmission losses which may occur in a telephone line from a remote program point are compensated for by a line equalizer.

The equalizer is associated normally with program circuit #1, but it may be connected to any of the other incoming circuits by use of a patching cord. Space and wiring are provided for the addition of a second equalizer.

Terminals for two outgoing transmitter lines are furnished, one for the regular transmitter and one for a standby transmitter.

A number of spare jacks and circuit terminals permit additions to or modification of the input and output circuits should these become necessary. Complete switching facilities are provided by four three-position lever type keys. These control the program circuits, announcing microphones, monitoring circuits, and output lines to the radio transmitter.

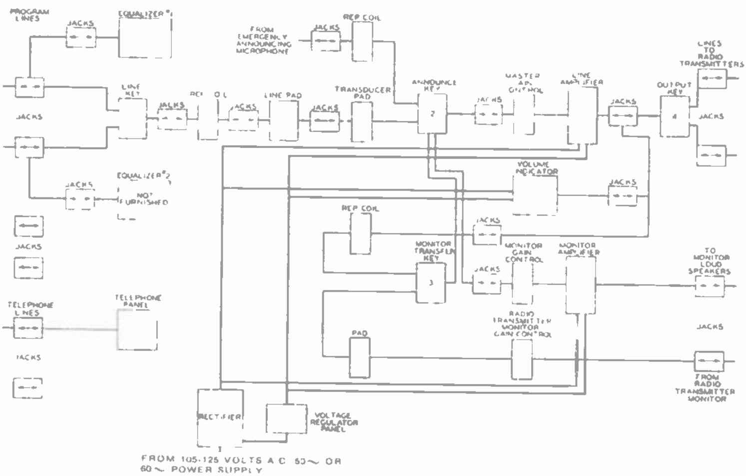


Fig.19 Block diagram of W.E. 15A speech input equipment.

Program levels throughout the system are controlled by means of a master gain control potentiometer associated with the line amplifier. A second gain control potentiometer is associated with the monitoring amplifier. A potentiometer is also provided for the radio transmitter monitor circuit to adjust the level from the radio transmitter monitor output[1] so that a direct comparison of the input and output of the transmitter can be obtained easily. The entire equipment is controlled manually by means of these three potentiometers, the four switching keys, and the master power switch of the rectifier.

Jacks at the necessary locations permit access to any part of the circuit. Patching cords and plugs are not required in the normal operation of the equipment, as the circuits are continuous through jack contacts.

The high level line amplifier and the associated master gain control potentiometer are identical electrically to the monitoring

[1] A radio receiver is generally kept in the control room permanently tuned to the transmitter frequency. This is called the "radio monitor."

amplifier and its gain control potentiometer and may be interchanged by means of patching cords in emergencies. The use of separate amplifiers for the monitoring circuit and for the radio transmitter circuit completely isolates the monitoring system from the transmitter feed. This eliminates the danger of short circuit or grounds in the monitoring system, causing similar trouble in the transmitter line. It also prevents noise from being introduced into the transmitter circuit, due to switching or other disturbances in the monitoring system.

The terminal strips and internal wiring for each panel are in the depressed part of the panel and may be exposed easily by removing the front panel mats (coverings). All of the apparatus on the back of the panels is completely enclosed and protected from dust and mechanical injury. The various panels are mounted in the cabinet in a manner which provides maximum convenience of operation. At the rear of the cabinet is a steel door with a locking device and a safety switch. The apparatus on the back of the panels is accessible through the rear of the cabinet. When the door is open, a safety switch automatically shuts off the main power supply and so protects the operator from contact with the high voltage.

Referring to the dimensional drawings of the 700A shown at C in Fig. 18, we shall describe the various pieces of apparatus employed.

(1) The 262A meter panel. The 262A meter panel contains a milliammeter for measuring the plate currents of the vacuum tubes in the 82A and 81A amplifiers. Push button keys are provided on the amplifiers for the purpose of making these measurements.

(2) 259A Switching Panel. On this panel are the four three-position lever-type keys which are used in switching the program circuits, announcing microphone, the monitoring circuits, and the output lines to the radio transmitter. The panel also contains the compensating and artificial line resistances used in the equipment, as well as the three repeating coils (matching transformers) which are parts of the complete system.

(3) 700A Volume Indicator. The 700A volume indicator is a single stage voltage amplifier and copper oxide rectifier unit which, with its calibrated meter, is capable of registering levels of -18 to +42 db in 2 db steps with mid-scale indication. Including the meter scale calibration, the extreme range of the energy levels measurable with this equipment is from -25 db to +45 db. It is of the highly damped type so designed that in following the envelope of the instantaneous peaks and valleys of sound, its indications closely correspond to the actions of the human ear. The indication given is therefore a true picture of the program level as a listener would hear it.

(4) 260A Telephone Panel. The 260A telephone panel provides terminal facilities for telephone communication with the radio transmitting station and remote pickup points. This panel may be used with a 206A hand telephone set, an operator's telephone set, or both simultaneously, if desired. A hand operated generator is used to signal the distant stations. A ringer responds to incoming calls.

(5) The 261A Control Panel. This panel contains three gain-control potentiometers which are used to control the energy levels in several parts of the system. One is the master gain control for the line amplifier, another is the gain control for the monitoring amplifier and the third is associated with the radio transmitter monitoring circuit to adjust the transmitter monitoring level to the input level for ready comparison.

(6) The 219 Jack Mounting. This panel occupies the space immediately above the removable writing shelf and contains the jacks necessary for testing and patching connections.

(7) The 992A Mounting Plate. This plate serves as a mounting for terminal strips, to which is connected the external wiring, such as the program lines, and the monitoring loud speakers.

(8) The 8A Rectifier. The 8A rectifier is a full-wave rectifier which contains two filter circuits. Plate power is supplied through one filter to the first 82A amplifier and through the other filter to the second 82A amplifier and the 700A volume indicator. In addition, terminals are provided for connection to 716A filter, required when a 81A amplifier is added to the equipment. The 8A rectifier unit includes a time delay relay which automatically delays the operation of the 274A (rectifier) vacuum tube until the filaments of the vacuum tubes in the amplifiers and the volume indicator have reached their normal operating temperature.

(9) 263A Voltage Regulator. This panel contains a voltage regulating transformer for supplying the AC at a constant potential of 10 volts to the filaments of the vacuum tubes in the amplifiers. The 263A voltage regulator is designed to operate from a 105 to 125 volts, 60-cycle AC supply.

(B) TYPE 81A PRE-AMPLIFIER. The Western Electric 81A amplifier is a two-stage resistance coupled amplifier, intended for use as a low-level pre-amplifier in AC operated speech input equipment. It is designed to operate from a 200-ohm input microphone circuit with a gain of 30, 40 or 50 db, as determined by the position of a flexible connector which is soldered to one of three resistance taps located directly behind the front panel. A schematic drawing of this amplifier is shown in Fig. 20. The frequency response characteristic is uniform within 1 db from 30 to 10,000 cycles. Two Western Electric 262A vacuum tubes are employed as amplifiers. The grid bias potentials for the vacuum tubes are obtained from the voltage drop across resistances R12 and R13, and R14 and R15, located in the cathode circuits of the first and second tubes respectively. Keys K1 and K2 are provided on the front of the panel for measuring indirectly the plate currents of the vacuum tubes through an external meter which should be connected to terminals 3(+) and 4(-) of the amplifier. For these measurements, the voltage across a part of the bias resistances in each vacuum tube circuit is measured on the external meter by depressing the proper key. An interlock circuit is provided so that the plate current of only one tube can be measured at any one time, even though the keys may be operated simultaneously. An external meter such as the Western Electric

262A meter panel should be used for measuring the plate current.

Care should be exercised in the installation of the 81A amplifier to guard against unnecessary exposure to strong magnetic fields from rectifiers or other AC operated equipment. Since the amplifier as ordinarily employed forms a part of a larger system, the

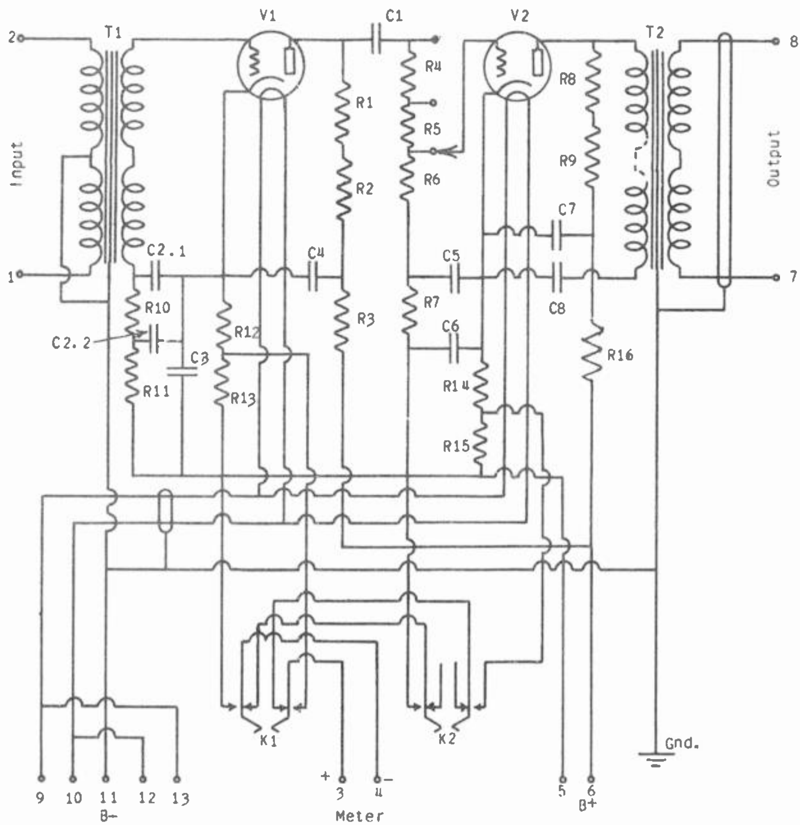


Fig. 20 Wiring diagram of W.E. 81A pre-amplifier.

gain of which may be as high as 100 db, it is obvious that any noise which is induced in the input circuit may become objectionable in the ultimate output of the system. Although special shielding precautions have been taken in the design of the amplifier, if the above precaution is not observed, an abnormal amount of hum due to magnetic coupling may be experienced. Two terminal strips are provided to isolate the AC filament leads from the input, output and plate supply wires.

All external connections to the amplifier should be made with shielded twisted-pair copper wire, and all joints should be securely soldered. The shield should be electrically continuous and grounded at the amplifier end by wrapping with several turns of #20 bare tinned copper wire, soldering and connecting the free end to the ground lug of the amplifier.

(C) The Western Electric 82A Program Amplifier. This unit is a two-stage, fixed gain, transformer-coupled amplifier intended for use in AC operated speech input equipment. It is capable of amplifying weak A.F. signals to a level suitable for feeding a telephone line, or the input level may be raised until the output is sufficient to operate a monitoring loud speaker.

The 82A amplifier is designed to operate between input and output impedances of 200 and 500 ohms respectively, with a gain of approximately 61 db and a frequency response characteristic which is essentially uniform from 30 to 10,000 cycles. The output transformer is tapped so that an output impedance of 250 ohms may also be obtained. It will deliver a +24 db energy level with less than 1% distortion. A schematic circuit diagram is shown in Fig. 21.

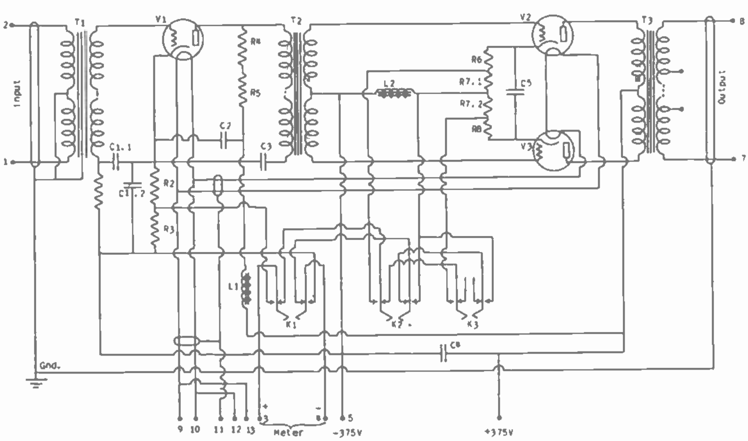


Fig. 21 Wiring diagram of W.E. 82A program amplifier.

A plate supply of 55 ma. at 375 volts is required for the plate circuits of the tubes. A W.E. 8A rectifier and filter is recommended for the purpose. Grid bias for the first A.F. stage is obtained from the voltage drop across R2 and R3 located in the cathode circuit of this tube. Bias for the second stage is obtained in the same manner, except that separate biasing resistances are provided for each tube in the push-pull amplifier. Keys are provided on the front of the panel for measuring indirectly the plate currents of each of the tubes through an external meter which should be connected to terminals 3 and 4. The W.E. 262A meter panel is designed for this purpose. For these measurements, the voltage across a part of the bias resistances in each vacuum tube circuit is measured by depressing the proper key.

The 82A amplifier does not include a control potentiometer, but may be used with any external potentiometer of suitable design. External connections should be made with shielded copper wire and the unit should not be exposed to strong AC electromagnetic fields.

(D) The Western Electric 94C Amplifier. This amplifier is designed for use as a high impedance, bridging-type monitoring amplifier. It has a self-contained AC power supply. It may also be used as a general purpose amplifier for application where a gain of approximately 45 db (on a 600-ohm input circuit) is ample, in all except low level circuits. The amplifier provides amplification for dynamic loud speakers and also has suitable gain for line use. A 45 db gain is secured when the amplifier is used to work from a 600 ohm input into a 500 or 8 ohm output load. The output power

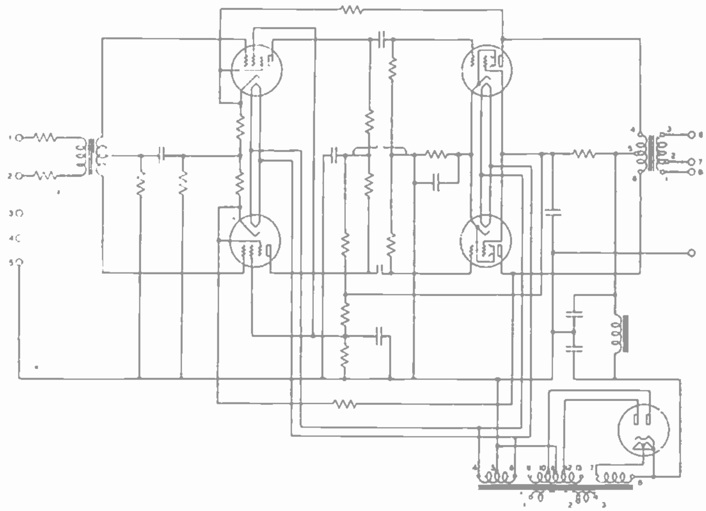


Fig. 22 wiring diagram of W.E. 94C monitor amplifier.

of the amplifier is approximately 12 watts with less than 5% total harmonic distortion. The noise level of the amplifier is from -40 to -60 db, and the frequency range is essentially flat between 35 and 10,000 cycles.

A schematic drawing of the 94C amplifier is shown in Fig. 22. The W.E. 94D amplifier is similar to the 94C except that it is equipped with a gain control potentiometer and a toggle power switch on the front panel. The 94C requires an external gain control and has the power switch under the chassis.

(E) The 104A W.E. Single Stage Pre-Amplifier. This is a high quality, low cost, fixed gain unit extremely compact and economical to operate. The gain is approximately 29 db. The frequency response is flat within 1 db from 30 to 10,000 cycles; the input impedance may be 30 or 250 ohms and the output impedance may be 30 or 500 ohms. Three of the 104A's are shown in Fig. 23A, mounted on a 998 type mounting plate. The three units occupy only 5¼"

space on a standard relay rack.

(F) The 105A Three-Stage High Gain Amplifier. A photograph of this unit is shown in Fig. 23B. It incorporates an inverse feedback system. The input impedances are 30 and 600 ohms and the output impedance is 600 ohms. The frequency response is flat with-

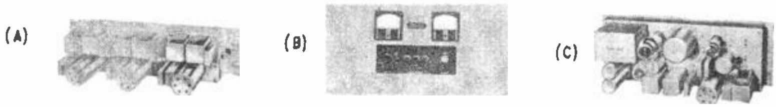


Fig.23 (A) Three W.E. 104A pre-amplifiers on a 5¼" panel. (B) Photo showing front view of W.E. 105A amplifier. (C) Rear view of W.E. 106A line amplifier.

in 1 db from 30 to 10,000 cycles, the overall gain approximately 70 db, with a range on the gain control of 38 db. The power supply is self contained, and the unit operates from a 105-125 volt, 50-60 cycle AC line. The distortion level is less than 1% at 400 cycles for a 20 db output. The noise level is from -55 to -65 db at maximum gain. The 105A amplifier includes a built-in volume indicator and a plate milliammeter. Push buttons are provided for measuring plate current in the three stages. The unit occupies 10½ inches of standard rack space.

(G) The 106A Two Stage Line Amplifier. This amplifier also incorporates the Western Electric system of stabilized (inverse) feedback. The input impedance may be 600 ohms, or 10,000 ohms for bridging across the output of the main amplifier. The output impedance of the unit is 600 ohms, the frequency response is flat within 1 db from 30 to 10,000 cycles, the overall gain is approximately 45 db, and the range on the gain control 38 db. The power supply is completely self contained and the unit operates from a

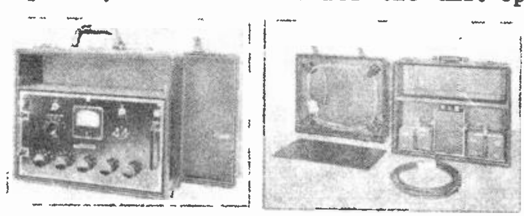


Fig.24 (A) Front view of W.E. 22A remote amplifier. (B) Power supply carrying case for W.E. 22A remote amplifier.

105-125 volts, 50-60-cycle AC line. The distortion level is less than 1% of 400 cycles for 20 db output. The noise level is from -60 to -75 db. The unit occupies 7 inches of standard rack space. A photograph is shown at Fig. 23C,

(H) The Western Electric 22A Remote Amplifier. This equipment consists of two units; one is a combination amplifier control unit and a carrying case, the other is a power supply unit and may contain a tube rectifier for AC operation, or a battery holder. The carrying case has ample capacity for carrying both AC and battery power supply equipment at the same time if desired. The amplifier control unit showing the arrangement of the dial switches

and volume indicator meter is shown at A in Fig. 24. B in Fig. 24 shows the power supply carrying case, arranged with the DC supply. Both cases are similar in size and appearance. The weight of the amplifier control unit is 15 pounds and the weight of the power supply using the AC power unit is 21½ pounds, with batteries, 26 pounds. Ample space is provided in both cases for microphone cords and other accessories. The covering of the cases is waterproof, black fabrikoid.

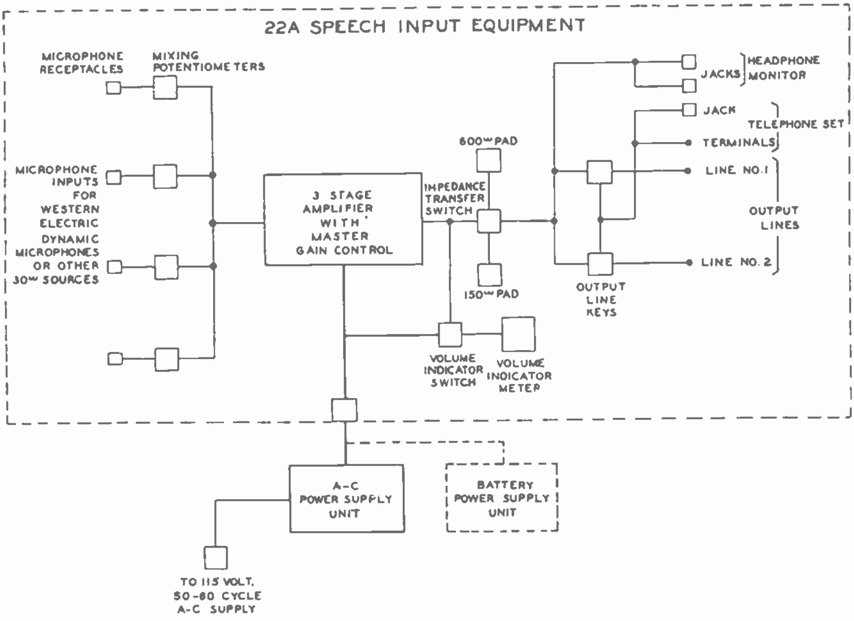


Fig. 25 Block diagram of W.E. 22A remote amplifier.

A block diagram of the remote control speech input unit is shown in Fig. 25. The maximum gain of the amplifier is approximately 92 db and the frequency characteristic is from 30 to 10,000 cycles. The input impedances of the microphone circuits are designed to match Western Electric's 30 ohm dynamic microphones; however, the gain is ample to permit the use of other modern broadcast microphones. The output impedance may be either 600 or 150 ohms. A maximum of control flexibility is obtained through the use of mixing circuits for the four microphones, plus a master gain control. Provisions are made for two monitoring head sets, one for the operator and the other for the announcer. Two output lines with keys are provided for connecting either the amplifier or the talk back telephone set to either line. This permits an instantaneous interchange of program and talking line circuits in case of emergency. The rear cover of the amplifier unit may be removed easily for access to the interior components. Two toggle switches are provided, one for the lamp which illuminates the V.I. meter and the other for the filament circuit. A rotary type volume indicator switch mounted on the upper left side of the panel changes the sensitivity of the volume indicator so that output levels from -4 db to +6 db may be measured. The same switch controls the meter so as to indicate the filament and plate voltages in order to check the condition of the battery. The output circuit includes a line isolation pad; it is designed to work into an impedance of either 150 or 600 ohms.

(I) The Western Electric No. 110A Program Amplifier. This unit is a volume limiting amplifier primarily intended for use in the program lines of radio broadcast stations at the transmitter locations. It is so designed, however, that it may be advantageously used at studios and other points in the broadcast system.

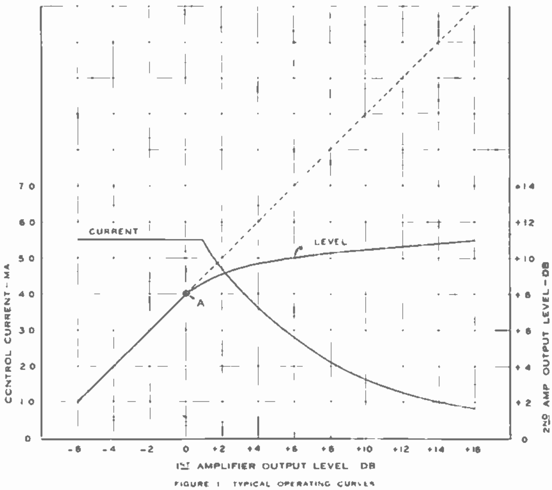
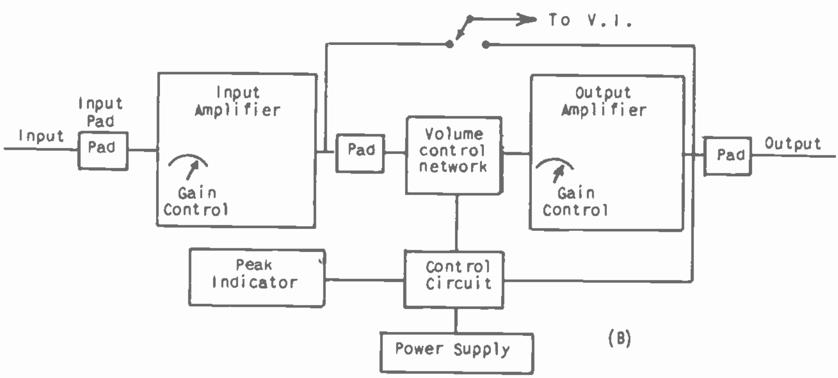


Fig.26 Graph illustrating the operating characteristics of the W.E. 110A program limiting amplifier.

When used in connection with a radio transmitter, the No. 110A Program Amplifier effectively reduces overmodulation, distortion, and adjacent channel interference caused by overmodulation. At the same time the average percentage of modulation may be increased, resulting in increased coverage for the radio transmitter. This is accomplished by the use of a volume control network which has characteristics similar to that shown in Fig. 26. In this figure, the levels designated "1st Amplifier Output Level - DB" correspond to the input to the volume control network and levels designated "2nd Amp. Output Level-DB" are directly proportional to the output of the volume control network. For input levels up to the point A, the relation between input and output is linear. For higher input levels, volume limiting occurs, and the output is no longer directly proportional to input. As a typical example of the method of operation, let us assume that the program amplifier is so adjusted that point A corresponds to an input level to the volume control network of 0 and an output level of the 2nd amplifier of +8 db. Thus, for all input signal levels up to 0 level, there is a net gain of 8 db. At point B, however, with an input level of +6 the output level increases to only +10 so the net gain is 4 db. Now if the output level at point B corresponds to 100% modulation of the transmitter, there will be a gain in the average modulation level of about 3 to 4 db. At the same time, input levels greater than +6 will cause no appreciable rise in output level above +10, hence the transmitter is protected against overmodulation. It is evident that volume compression occurs at the high level portions of the program which correspond, in the illustration, to input levels above 0. The amount of volume compression which is obtained is determined by the gain adjustments of the equipment.

(A)



(B)

Fig. 27 (A) Photograph of W.E. 110A program limiting amplifier. (B) Block diagram of circuit in 110A amplifier.

The 110A "limiting" amplifier is designed for input levels in the range from -35 to +5 db, and it will furnish output levels up to +20 db. It operates from a 105-125 volt 50-60 cycle AC supply. The panel is $19\frac{5}{32}$ inches wide, $19\frac{7}{32}$ inches high, and $7\frac{1}{2}$ inches deep. The depressed panel type of construction is employed, thus making all apparatus readily accessible. A photograph is shown at Fig. 27A.

A block diagram of the equipment is shown at B in Fig. 27. The equipment comprises an input amplifier, a volume control network, an output amplifier, and a power supply.

The volume control network is essentially a variable-loss resistance pad using silicon carbide "varistors" for the pad elements. The resistance of silicon carbide is a function of the impressed voltage, and this property is utilized to obtain loss variation.

A simplified schematic diagram of the volume control network and its associated vacuum tube control circuit is shown in Fig. 28. (For convenience plate and bias voltages are shown supplied by batteries in this diagram. All voltages are actually obtained from the power supply.) The vacuum tube control circuit is connected to the output of the variable loss network and consists of an audio amplifier V5, a full wave detector V6, and a d.c. amplifier or control tube V7. The control tube plate current flows through the varistor pad elements R1 and R2 and its magnitude determines the

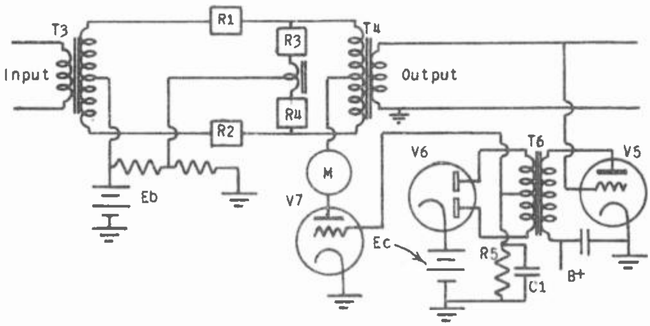


Fig.28 Simplified diagram of volume control network in W.E. 110A program amplifier.

loss of this pad. Some of the plate current also passes through R3 and R4 to vary their resistance values. R3 and R4 are used to keep the impedances properly matched from T3 to T4 as R1 and R2 are varied by the control current. In effect, this circuit is similar to a variable T pad. For all inputs up to an input level corresponding to point A of Fig. 26, this current is constant and of sufficient magnitude to reduce the loss of the pad to approximately 3 db. For larger inputs, the output will be sufficient to overcome the bias Ec on the detector V6, current will flow in the detector circuit, and a negative charge will be placed on the grid of V7. This will decrease the plate current of V7 and increase the loss of the varistor pad. Thus, for inputs greater than that corresponding to point A of Fig. 26, the pad loss will increase and volume limiting will occur. The rate at which the pad loss is increased or decreased is determined by the time constant of the resistance and capacity R5 and C1 in the detector circuit. In the No. 110A Program Amplifier, the operator may choose either of two values for condenser C1 by operating a toggle switch.

Associated with the control circuit is a peak indicator which may be adjusted to operate a signal lamp when a predetermined amount of additional loss has been inserted in the volume control network. By observing the frequency of operation of the lamp, the operator can check the general adjustment of the equipment.

Since the characteristics of the volume control network are determined by its design, it is necessary to restrict the input levels to this network to the proper range. In order to comply with this requirement and to provide flexibility of control and satisfactory overall performance, audio amplifiers are used ahead of and following the volume control network.

Both the "input" and "output" amplifiers consist of two resistance coupled stages employing stabilized feedback. A schematic drawing is shown in Fig. 29. The "input" amplifier is designed to work from a 600 ohm balanced line and the "output" amplifier is designed to work into a balanced load of 600 ohms. Both amplifiers are provided with pads and gain control potentiometers to secure the proper operating levels. The gain control potentiometers each have 19 one db steps.

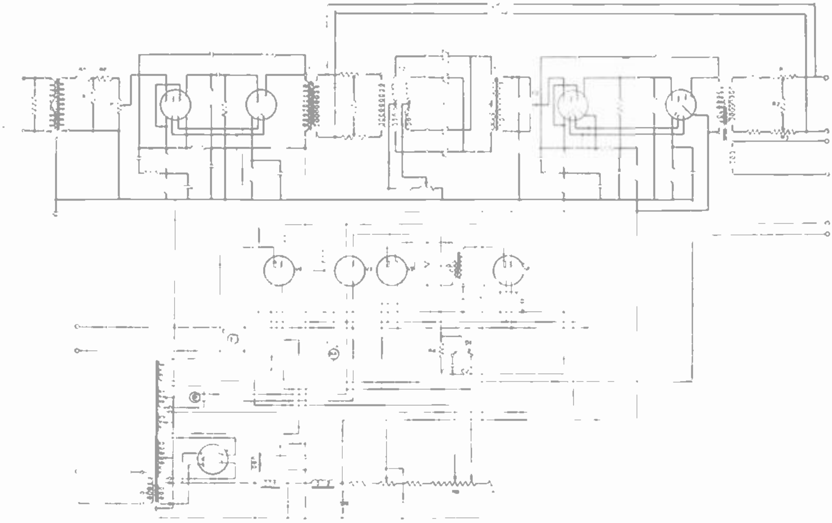


Fig. 29 Schematic diagram of W. E. 110A program limiting amplifier.

Terminals are provided on the equipment for the connection of a Volume Indicator. This instrument is not furnished as part of the equipment.

THE COLLINS SPEECH INPUT EQUIPMENT

(5A) The 7S Amplifier. The Collins 7S is a general purpose amplifier, finding wide application in modern studio installations. Its attractive appearance, wide range of uses, ease of installation and excellent performance are some of its outstanding features. A front view of the 7S amplifier is shown in Fig. 30.

The 7S amplifier incorporates two voltage amplifier stages, a push-pull output stage, and a rectifier-filter system. All amplifier tubes are connected as triodes for minimum distortion and increased signal handling ability. The use of highest quality component parts, carefully tested before assembly and operated at a fraction of their rating, reduces maintenance to a minimum. Straightforward electrical circuits, time proven in Collin's amplifiers, gives excellent performance and fidelity.

The 7S may be used as a line amplifier, monitor amplifier, audition amplifier, or for any other medium level or high level amplifier application. The use of one model of amplifier for several purposes simplifies maintenance and gives increased standby protection.

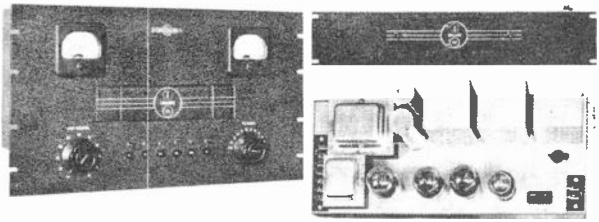


Fig.30 (A) Collins 7S general purpose amplifier. (B) Collins 6F pre-amplifier. (C) Collins 7R Bridging amplifier.

The gain of the amplifier is 83 db or 63 db, when used as a line amplifier, 57 db or 37 db when used as a bridging amplifier. Input provisions are made for impedances of 200, 500 or 10,000 ohms. The output impedance may be either 200 or 500 ohms. The noise level is -50 db at maximum gain, and the frequency response is flat within 1 decibel from 30 to 10,000 cycles.

(B) The 6F Pre-Amplifier. The 6F pre-amplifier features a universal input impedance, gain sufficient for any microphone, full accessibility of parts, and attractive appearance. Used with the 7S amplifier and suitable mixing facilities, the 6F provides a truly high fidelity microphone amplifier channel.

The gain of the amplifier is 61 decibels, input impedance provisions are made for 30, 50, 200, 250 ohms, or direct to the grid of the tube. The output impedances are 200 or 500 ohms. The frequency response is flat within 1 db from 30 to 10,000 cycles and the noise level is -70 db. A front view of the 6F pre-amplifier is shown at B in Fig. 30.

(C) 7R Bridging Amplifier. The 7R is an economical speaker amplifier intended for use with 0 level audio distribution systems. Its low cost allows a separate amplifier to be used for each loud speaker, and its small size allows it to be mounted in the loud speaker cabinet or baffle. The input impedance is 20,000 ohms and the output impedance is 500 ohms, with taps at 3, 8 and 15 ohms. The gain is 31 db, which is sufficient to give full output from 0 level input signal. The power output is 2 to 8 watts according to the type of output tubes used. The volume can be regulated by the control on the chassis or a remote volume control can be used. A top chassis view of the 7R bridging amplifier chassis is shown at C in Fig. 30.

(D) The Collins 12F Speech Input Assembly. The Collins 12F speech input assembly is designed specifically to meet the requirements of broadcast stations desiring to transmit, monitor and

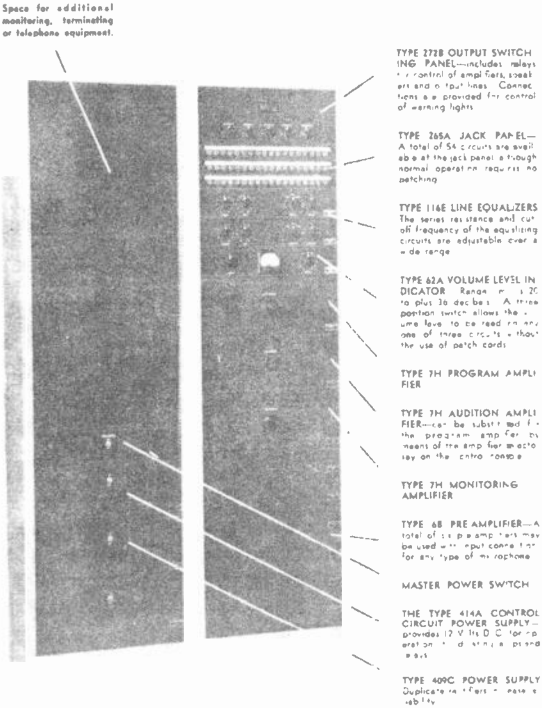


Fig. 31 Collins Type 12F speech input assembly.

rehearse programs with one set of equipment. The arrangement of the apparatus in the 12F assembly is illustrated and labeled in Fig. 31. A 60L mixing and control console is shown at A in Fig. 32. This unit is to be connected by cable to the 12F assembly. It is equipped with all of the operator's controls, circuit pilot lights, and extension volume indicator.

The 60L mixing panel incorporates 6 input attenuators, 6 input selector keys, 2 master gain controls, 1 amplifier selector key, 1 line key, 1 monitor key, and 18 indicating lamps. Appropriate designations are engraved in the control panel. Full information is available from the manufacturer.

(E) The Collins 12X Remote Amplifier. This amplifier is a compact, high-gain, three channel amplifier for remote pickup service. The complete assembly includes amplifier, power supply, inter-connecting cables, spare tubes, monitor headphones, and one or two microphones, all carried in a single case 10" × 15" × 19".

The 12X amplifier incorporates a separate pre-amplifier stage ahead of each channel in the mixing circuit. A tapped input transformer in each channel allows any type of low level microphone to be used, except those requiring a polarizing voltage. The frequency

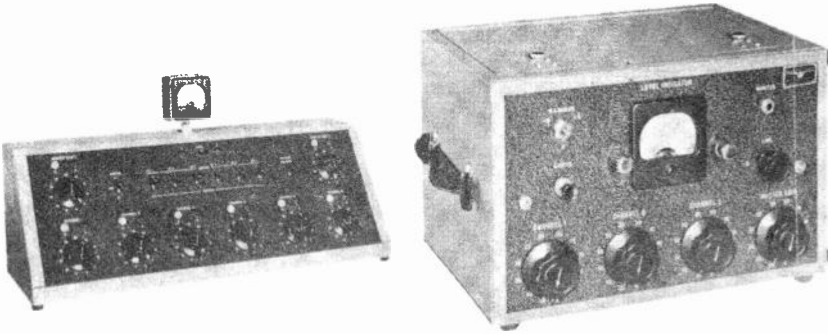


Fig.32 (A) Collins Type 60L mixing panel for use for 12F speech input assembly. (B) Front view of Collins 12X remote amplifier.

response is essentially the same for all input impedance connections. The master gain control is located in the grid circuit of the third stage. The volume indicator is of the high speed type, with a switch for selecting three ranges and an "off" position. Two surface lights illuminate the meter and control panels. A front view of the 12X remote amplifier is shown at B in Fig. 32. Ample power output is assured by the use of a push-pull output stage which gives low distortion at normal operating levels. For AC operation, the type 412A power supply is designated for use with the 12X amplifier to operate from 110-volts, 50-60 cycle AC source.

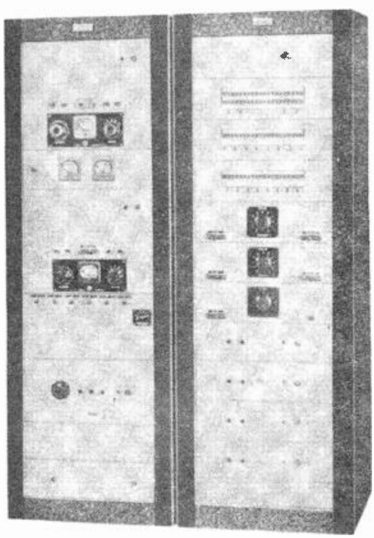
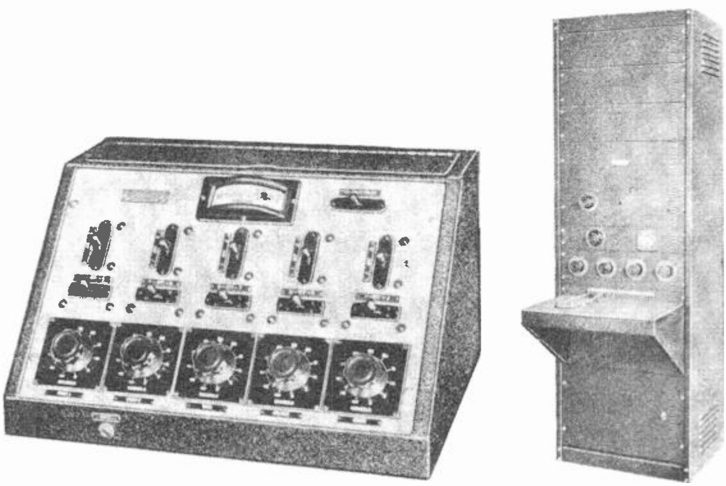


Fig.33 Gates model SIE-27 speech input equipment.

The hum and noise level is at least 50 db below the signal level at normal gain control settings and the frequency response is uniform within 1 db from 30 to 10,000 cycles. Input impedances of 30, 50, 200 and 250 ohms, or directly to the grid of the input tube are provided. The output impedance of the amplifier is 500 ohms. The overall gain is approximately 100 db.

6. THE GATES SPEECH INPUT EQUIPMENT. A photograph of the Gates dual rack cabinet assembly model SIE-27, to be used with the SIE-26 control console is shown in Fig. 33. The left rack in this figure includes two program amplifiers, a monitoring amplifier, a 6 position talk-back panel, meter panels, and a rectifier for relays and pilot lights. The right rack equipment includes four pre-amplifiers, three equalizers, a 100 position jack patch system, and the pre-amplifier power supply. Photograph A in Fig. 34 shows the SIE-26 control console to be used in conjunction with the SIE-27 rack equipment.



(A) (B)

Fig.34 (A) Gates model SIE-26 control console. (B) Gates model 600A speech input assembly.

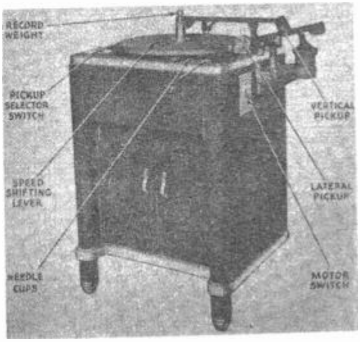
Another of the low price, high quality, commercial speech input systems in the Gates line is the type 600A installation. A photograph of this complete unit is shown at B in Fig. 34. It consists of three two-stage pre-amplifiers, a three-stage, push-pull amplifier, a modern V.I. panel, a four channel mixing panel, a 20 position jack strip, control desk and a power supply. All this is built into a rack, completely wired and ready to operate. This speech input system is experiencing wide popularity in the smaller stations and in large stations for sub-control room installation. The Gates Radio & Supply Company of Quincy, Illinois have a complete line of broadcast station equipment and accessories available.

Descriptive information may be obtained from the manufacturer upon request.

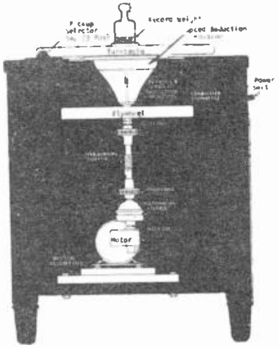
THE RCA SPEECH INPUT EQUIPMENT

(A) The Type 70A Transcription Turntable. The RCA type 70A transcription equipment is assembled complete in a console type cabinet. The console is 31 inches high and approximately 20 inches square. A photograph of the unit is shown at A in Fig. 35.

A 16 inch felt covered cast aluminum turntable is provided. Since many of the transcriptions used are of thin material with a consequent tendency to warp, a special weight is provided to make them lie flat. This weight, which has a soft rubber face next to the record, engages the hexagonal record spindle, and thus assures a positive drive between the turntable and the record. A small positive acting sliding button is cut in the slot on the top of the turntable by means of which the change in speed from 33⅓ to 78 rpm is affected.



(A)



(B)

Fig. 35 (A) RCA type 70A transcription turntable. (B) Outline drawing illustrating internal construction of 70A.

The main turntable spindle revolves constantly at 78 rpm. When 33⅓ revolutions is desired, a change in the speed shift button intersects the direct drive from the motor and through a ball bearing reduction clutch, the speed of the turntable is reduced. An outline drawing of type 70A mechanism is shown at B in Fig. 35. A rugged iron housing set in the top of the cabinet supports the clutch mechanism and the main turntable spindle. A large stabilizing fly wheel is fixed to the spindle just below the housing. The whole housing is felt insulated from the cabinet top in order to prevent the torque vibration of the motor from being conducted from the turntable through this housing to the pickup arm. An oil hole located in the top of the record spindle on the turntable provides for lubrication of all bearing surfaces.

In any reproducing equipment, speed constancy is an essential requirement. Unless the regulation of the driving motor is such that variations of the load imparted by the pickup and suspension arm do not appreciably affect the motor speed, there is a tendency to produce "wows" on the sustained notes of low frequency. This is a type of distortion that is particularly noticeable in broadcast transmission, and it is therefore absolutely necessary that transcription equipment for broadcast use be supplied with a driving motor having extremely good speed regulation. In the type 70A transcription equipment, considerable attention has been given the problem of obtaining the very best possible regulation. Driving power is furnished by a self starting synchronous motor of sufficient size that the torque developed is large compared to the load variation and the effect of the latter is therefore small. Slight irregularities which may occur in the motor or in the load are stabilized by the large fly wheel shown in Fig. 35B.

The lateral and vertical reproducing systems of this equipment are entirely independent. The lateral pickup and suspension are mounted on the right side of the console; the vertical pickup and suspension arm at the rear. (Fig. 35A is a front view.) The mountings, which are similar, consist of cast metal brackets rigidly fixed to the cabinet. These brackets have two arms, one is formed into a swivel cup in which the suspension arm support is cushion mounted. The other forms a rest for the pickup end of the arm when not in use. Long suspension arms are provided to obtain good tracking for both the largest and the smallest records. These arms are of the inertia type and are correctly balanced to assure correct needle pressure for each type of pickup. The lateral arm has additional weighting to eliminate resonance.

The lateral pickup is of a magnetic design especially developed for transcription and other high quality pickup. The actual frequency response characteristic of this pickup is sloped downward to an amount closely equivalent to the upward slope of present day recording characteristics. This compensation results in an overall record reproduction characteristic almost uniform throughout the whole useful range; that is, from about 30 to 7,000 cycles.

The vertical arm attachment (kit type 71A) for use with the 70A transcription equipment is of the moving coil type and is supplied with a diamond point needle. As is the case of the lateral pickup, the frequency characteristic of the vertical pickup is sloped downward to correctly match the upward sloping recording characteristics. The characteristic extending as it does to 10,000 cycles insures excellent reproduction fidelity.

The output impedance of the two reproducing circuits and the output levels developed across these impedances are very nearly the same so that they may be used interchangeably without change of connections or gain in the succeeding speech input equipment. These circuits are designed to match a 200 to 250 ohm line.

The switch controlling the power to the motor is located on the right side of the cabinet at the top toward the front. It is a mercury switch of the tumbler type, noiseless in operation. The pickup selector switch located at the left on the top of the cabinet is a three position switch, with detents for positive contact. The right hand and center settings of this switch correspond to the relative positions of the two pickups. The left hand setting provides for the possible later addition of a third pickup system, or it may be used when the lateral pickup is placed on the left of the cabinet. The speed shift control, as mentioned before, is mounted in the turntable proper, and is plainly marked with two colors, as well as with numerals corresponding to the two speeds.

(B) The RCA DeLuxe Speech Input Panel. Fig. 36 shows a control panel equipped with the latest RCA speech input equipment. The various panels on the rack are labeled so we shall proceed to discuss each unit separately.

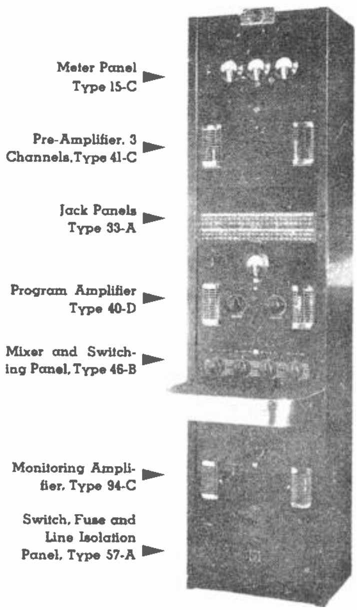


Fig. 36 RCA Deluxe speech input panel.

In the type 15C meter panel, each of the instruments is provided with an illuminated dial. The three instruments are an 0 to 250 DC voltmeter, an 0 to 150 AC line voltage meter, and a dual range milliammeter, 0 to 10 and 0 to 100 mills DC. With these meters, it is possible to measure the plate currents and plate voltages on all of the amplifier units, in addition to checking the line voltage.

The 41C three channel pre-amplifier unit is shown next in the RCA equipment. In this unit, there are three separate pre-amplifiers entirely independent of each other except for the common power supply connection. Each consists of an input transformer, a two-stage resistance coupled amplifier, and an output transformer. The circuits of these amplifiers have been laid out to insure complete stability and at the same time, every circuit provision has been made which might add to the fidelity of reproduction. The three input transformers have been tapped so they may be used with either a 50 or 250 ohm microphone. The output transformers have 250 ohm and 500 ohm connections. Provision is made in each amplifier so that its gain may be independently adjusted to be 40 db or 32 db for use respectively with different types of microphones.

The six tubes used in the three channels of the 41C pre-amplifier are RCA 1603's. These are multi-element tubes which have been especially developed for use in RCA low level speech input units. Every tube is tested to insure that it has a low hiss, low hum content, and is non-microphonic. Other features in the design of the amplifier to insure low noise level include careful shielding and arrangement of the circuit, encasement of transformers in heavy nicaloi housing, shock-mounting of tubes, and use of extra large by-pass condensers in all supply leads. As a result, the noise level is at least 60 db below the normal signal level. The frequency range is flat from 30 to 10,000 cycles.

(C) Type 33A Jack Panels. Two double row jack strips are provided which permit the termination of 48 input and output circuits. Each position has a tab above it which can be used for labeling.

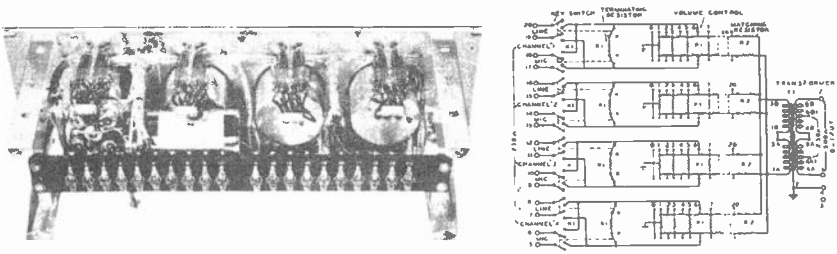
(D) The Type 40D Program Amplifier. This attractive line amplifier unit provides the amplification necessary to raise the mixer output to line level. It also contains a V.I. meter mounted in the top center of the front panel.

The amplifier section of the 40-D amplifier employs four tubes, an RCA 1603, pentode-connected in the first stage, an RCA 1603, triode-connected in the second stage, and a pair of RCA 89's push-pull in the output stage. The master gain control is connected between the first and second stages. The use of the three stages gives the 40D amplifier an overall gain of 75 db, which is sufficient, in case of emergency, to operate directly from a low level microphone into the line. The push-pull output stage provides a relatively high output with low distortion, only .2% at normal output. While the normal output of the amplifier, as ordinarily used, will be 0 db, it is capable of furnishing outputs up to plus 18 db without noticeable distortion. The frequency response is essentially flat within 1 db from 30 to 17,000 cycles.

The V.I. system in the 40D makes use of a three-tube circuit, separate from the amplifier. A special winding on the output transformer drives an RCA 6A6 amplifier-phase-inverter which is coupled to an RCA 84 connected full wave. The latter rectifies the audio frequencies, allowing only the envelope variations to pass through. This voltage is impressed on the grid of an RCA 76 connected as a vacuum tube voltmeter with the V.I. meter in the plate circuit. The V.I. meter itself is of the high speed type. Thus it swings up very rapidly, and gives an accurate indication even on the shortest peaks. However, instead of returning quickly to zero--which would make reading almost impossible--it drops off from the peak reading very slowly, thus giving the so-called "floating" reading which makes monitoring more accurate.

The input impedance of the 40D amplifier may be changed to accommodate either 250 or 500 ohms; likewise the output impedance may be 250 or 500 ohms. The 40D is intended to be used as the main program amplifier in assemblies of equipment where it will ordinarily be preceded by a 41C pre-amplifier.

(E) The Type 46B Four Position Mixer. The Type 46B mixer panel provides for mixing four microphone inputs and for direct switching of these with four turntables or line inputs. The unusual facilities of the 46B panel are due primarily to the use of a three position key switch in the input of each of the four mixers. These switches are located just above the corresponding mixer, as shown in Fig. 36 and at A in Fig. 37. B in Fig. 37 is a simplified schematic showing the internal wiring of the 46B mixer. When thrown to the left, these switches connect the corresponding mixer to one set of input connections and to the right to a different set. In the center, they connect a 250 ohm resistor across the input, thereby automatically closing that channel. The arrangement makes possible a wide choice of operating combinations.



(A) (B)

Fig.37 (A) Rear view of RCA 46B mixing panel. (B) Simplified schematic of the RCA 46B mixing panel.

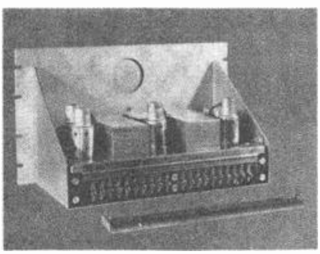
Four individual mixers of the balanced H variable-ladder type are employed. They have 20 contacts providing for increase in attenuation in 2 db steps, up to the last step, which shorts the input, thereby providing infinite attenuation. Each mixer is enclosed in its own shield, in order to prevent dust from entering. The rear view of the panel with the shield removed is shown at A in Fig. 37.

(F) The RCA Type 94C Monitoring Amplifier. The 94C monitor amplifier has an undistorted power output of 20 watts, which makes it possible, if desired, to drive several monitoring speakers with this one amplifier. A total gain of 80 db is provided and the frequency response is guaranteed to be within 1 db from 30 to 17,000 cycles. The distortion at maximum output is less than 5½%.

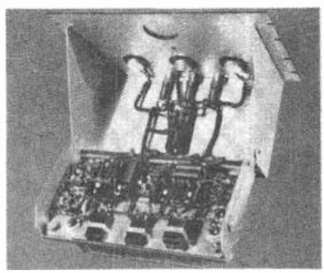
In the electrical design of the circuit, four push-pull stages are employed. The input transformer has primary taps providing impedances of 500 ohms and 20,000 ohms. The RCA 1603 in the first stage is resistance-capacity coupled to a second stage employing a pair of RCA 1603's in push-pull. These are in turn resistance-capacity coupled to a third stage, using a pair of RCA 89's. These are transformer coupled to the final stage which consists of four 2A3's in push-pull parallel. The output transformer has secondary taps to match 7½, 15 or 500 ohms. A bridging type volume control is provided which has an input impedance of 20,000 ohms and an output impedance of 500 ohms. This volume control may, if desired, be mounted externally at some distance from the amplifier. The plate voltages for all stages are furnished by a built-in rectifier which uses a 5Z3 in a full-wave circuit. The circuits are arranged so that the field coils of two speakers may act as filter chokes.

(G) The RCA Type 58A Tri-Amplifier. In keeping with the modern trend toward electronic mixing, the 58A tri-amplifier provides three channel pre-amplification, mixing, and switching; thus, simplifying the speech input assembly. Formerly it was necessary to provide a pre-amplifier unit for each microphone input, a separate mixer unit, and other facilities for switching and control. The type 58A tri-amplifier provides in itself the same facilities; that is, it replaces at least four units. Much inter-unit wiring is thus eliminated, and the likelihood of noise and hum pickup is reduced.

A single RCA 1603 pentode is used as a triode in each of the pre-amplifiers. Special transformers with alternative primary impedances of 50 and 250 ohms provide the input connection to each of these while the outputs are resistance-capacity coupled to 3 double throw switches. The 3 line inputs terminated in 250 ohms, are connected to the opposite sides of the three switches. The mixing system is of simple design and makes use of three potentiometer type controls. The combined output of the three mixers is then coupled into the grid of a fourth RCA 1603 which functions as the output tube of the unit. Output impedances of 250 and 500 ohms are provided. The overall gain of the unit is 30 db, and an external plate supply of 180 volts at 12 milliamperes is required. Closed and extended rear views of the 58A are shown in Fig. 38.



(A)



(B)

Fig.38 (A) Rear view of RCA type 58A tri-amplifier. (B) Rear view showing type 58A amplifier opened for inspection.

(H) The RCA 96A Limiting Amplifier. A simplified schematic of the 96A limiting amplifier is shown in Fig. 39. The essential function of this amplifier is the same as that of the Western Electric 110A; that is, to serve as an automatic means of limiting the upper peaks of the audio signals as fed into the radio transmitter. This, of course, means a marked reduction in the amount of gain riding, which must be done by the control operators and serves as an automatic protection against overmodulation. A front view of the 96A amplifier with the door closed is shown at A in Fig. 40,

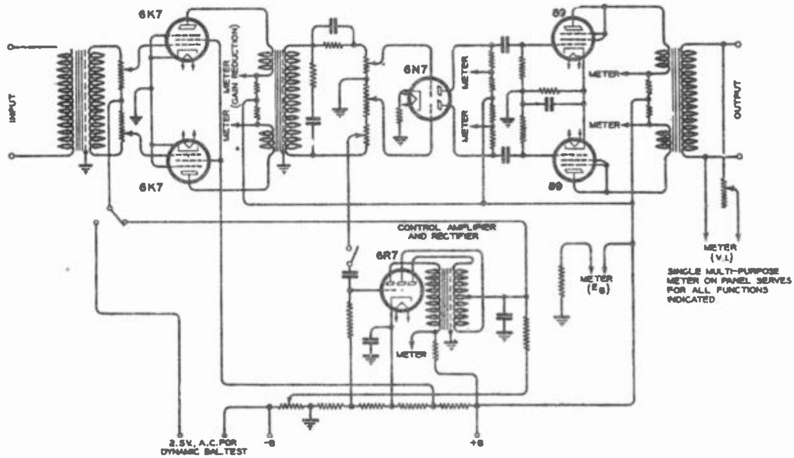
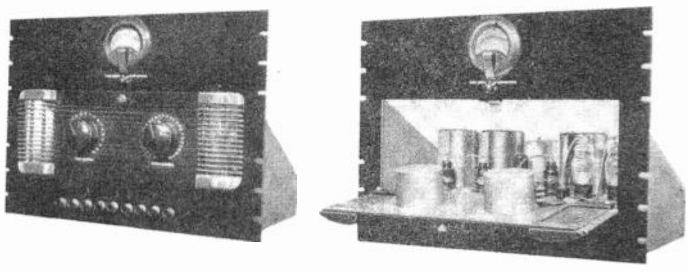


Fig.39 Wiring diagram of RCA 96A limiting amplifier.

while B shows the front door open to indicate the easy accessibility to all of the amplifying tubes. A standard rectifier type V.I. meter is built into the chassis. It is provided with a selector switch so that it may be used as a volume indicator, as a compression indicator, or for metering. As a volume indicator, it indicates the level of the A.F. variations as fed to the transmitter. As a compression indicator, it provides a continuous reading in decibels of the gain reduction on peaks of the audio signal. The input and output amplifier controls are on the left and right respectively of the door. The input control has a total attenuation of 40 db in 2 db steps. The output control provides a total attenuation of 28 db in 1 db steps. Metering is accomplished entirely by push buttons, thereby eliminating the use of patch cords. The nine buttons arranged along the bottom of the panel provide for reading all plate currents and plate voltages. In addition, means are provided for



(A) (B)

Fig.40 (A) Front view of RCA's 96A limiting amplifier. (B) 96A limiting amplifier with front door open.

obtaining a dynamic check on the amplifying tubes in terms of the V.I. reading, when a small AC voltage is introduced in the bias circuit. A separate power supply unit must be used with the 96A amplifier.

The amplifier proper consists of three push-pull stages and the control tube is an RCA 6R7. The 6R7 is a multi-purpose tube having a triode section and a diode section in the same envelope. Referring to Fig. 39, the grid of the triode section is fed a portion of the audio voltage passing through the amplifier. This is obtained from a potentiometer across the secondary of the transformer between the first and second stages. In other words, the connection is essentially across the output of the first stage. The signal voltage, having been amplified by the triode section in the 6R7 is rectified in the diode section. The resulting DC voltage appears across a resistor, which is in series with the bias voltage supplied to the grids of the 6K7's; that is, the variable-mu tubes in the first stage of the amplifier. Thus, as the signal increases, the bias voltage on these tubes will become more negative, and their amplification factor decreases. This, in turn, reduces the output of these tubes and the output of the amplifier. Since it is not desired to reduce the gain at low input levels, the relation of the several voltages is made such that the gain control does not begin to function until the audio signal applied to the control tube, the 6R7, exceeds the fixed bias of the latter. This, of course, occurs at a fixed voltage level. However, the corresponding input level to the amplifier at which this control starts can be altered by varying the input control, a potentiometer across the secondary of the input transformer. Because of the high gain, 58 db, incorporated in this amplifier, this point; that is, the beginning of compression, may be as low as -40 db. Similar provision for adjustment of output is secured through the output gain control, which is a potentiometer in the input of the second amplifier stage, The output level can be set by means of this control anywhere within the range of -10 db to plus 18 db.

Another important feature of the amplifier is the time constant. Since the control circuit must function very quickly in order to compress sudden peaks, the circuits are arranged so that the reduction in gain occurs almost instantaneously, (.001 second). At the same time, it is not desirable to have the gain fluctuate on low audio frequencies, or at syllabic frequencies. To prevent this, a slowly discharging circuit is provided so that the voltage applied to the 6K7 leaks off relatively slowly. The return to normal gain requires about 7 seconds. These time characteristics have been worked out very carefully and have been adjusted to insure that they are correct, and will not introduce distortion or destroy normal speech inflection.

(I) Space does not permit a further description of the RCA equipment available for broadcast purposes. Many more units are included in the complete RCA equipment line and for those interested in obtaining additional information on the equipment herein described or information on other RCA products may communicate with the Transmitter Division of the RCA Manufacturing Company, Camden, New Jersey.

8. THE WESTERN ELECTRIC 23B CONTROL CONSOLE. This equipment is a novel fulfillment of the need for a complete single unit of speech input facilities. It is assembled in a console type cabinet, low enough to be mounted on a table without obstructing the view of the operator. This new equipment presents a rare combination of flexibility, simplicity of operation and high quality performance. Its compact assembly, ease of operation and absence of inter-bay wiring makes it especially suitable for use in the studio installation for a smaller station. The noise level of the overall system is 61 db below the program level and the frequency response is within 1 db from 30 to 10,000 cycles.

The complete equipment, including amplifiers, volume indicator, power supply and switching circuits, is contained in a single metal cabinet, factory wired and tested, as shown in Fig. 41. The cabinet is 34" wide, 14" deep, 10" high, and weighs complete, approximately 110 pounds.

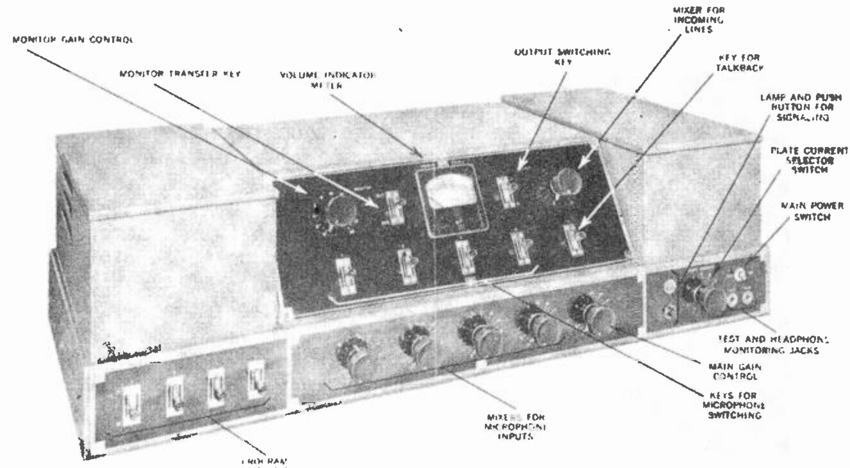


Fig. 41 Photograph of Western Electric 23A control console.

The main control panel is situated in the center of the cabinet. The upper section of this panel is sloped so that the illuminated volume indicator meter mounted in the center can be easily read and to facilitate manipulation of the switches and the main gain control. At the lower part of this panel are a talk-back key and four microphone switching keys. Above these, to the left of the volume indicator meter are the monitoring gain control and monitor-transfer key. On the right are the output switching key and mixer for incoming lines.

The four program line keys are on the left-hand side of the vertical base section. In the center are four mixing potentiometers, and the main gain control on the right side are the main power switch, the headphone monitoring jack, plate current selection switch and jack, and a push button and lamp which may be used as part of a signalling circuit if desired. The block schematic diagram of this speech input equipment is shown in Fig. 42. Each of the four microphone switching keys is wired to accommodate two microphones. With the key in the up position, the microphone in one studio is connected. With the key in the down position, the microphone is disconnected and another microphone in another studio or in the same studio, if desired, is connected. With the key in the intermediate position, both microphones are off. Each key has contacts for operating a loud speaker cutoff relay, so that it is impossible to have both the microphone and loud speaker operating at the same location, and to control supplementary external relays

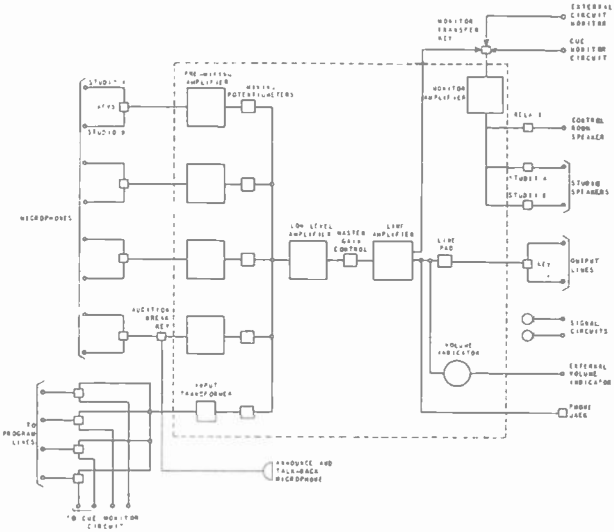


Fig. 42 Block diagram of Western Electric 23A control console.

for studio silence and warning lights. These contacts are connected to terminals on the terminal strip so that various combinations of operating conditions can be obtained by proper connections.

The "talk-back" key enables the operator to communicate with the studio through the loud speaker system, or to make local announcements from the control room. When this key is operated to the "up" position, the studio microphones and the control room loud speaker are disconnected and the control room microphone and studio loud speakers are connected. In this position, the control room microphone is connected through the pre-mixing amplifier to a mixing potentiometer.

The four program line keys provide sufficient facilities for an operator to select any one of four remote broadcasts at will. Any one of these keys operated in the down position connects the associated program line to the input of the mixing circuit. Operated in the "up" position, it connects the line for preliminary monitoring. Both the monitoring terminals and the line terminals of the keys are wired to terminal strips in the rear. Where more than four program lines are required, the incoming lines may be terminated on a separate jack or key panel and trunks run from this panel to the keys on the 23-B equipment. Lines for remote broadcasts must be set up in advance and the actual program switching performed at the convenience of the operator at his regular position. The fact that all leads from these keys are brought out to an accessible terminal strip on the rear of the equipment makes it possible to secure the best combination for any given installation.

Each of the five mixing potentiometers has 20 steps of attenuation, 17 of which are 1.5 db each with increasing attenuation on the last three steps to cut-off. Each of the four mixing potentiometers associated with the microphone circuits has an amplifying stage preceding it. The output of the mixers is amplified through a single amplifier terminating in a master gain control, which is followed by two additional stages of amplification.

The output of the amplifier goes through a resistance pad designed to work into a 500 or 600 ohm circuit. The constant output level of the line amplifier is +15 db and the volume indicator is calibrated at this level. The pad furnished results in a +10 db level to the connected circuit. For lower output levels the attenuation of the output pad may be increased by subusituting standard resistances which are interchangeable with the ones in the equipment.

The monitoring amplifier input is connected to the monitor transfer key. This is a three position key which may be used to connect the monitoring amplifier to the output of the line amplifier for normal monitoring, to a pair of terminals which may be connected to an external circuit such as a radio transmitter monitor, or to a second pair of terminals which may be connected to the incoming program lines for cue monitoring.

The output of the monitoring amplifier is designed to operate into a 750 ohm circuit. The output of this amplifier may be arranged to operate three 250 ohm loud speakers connected in series. Under this condition, approximately .5 watt of power may be supplied to each speaker with about 5% total distortion. Three loudspeakers cutoff relays function automatically under control of the microphone key to prevent operation of a microphone and loud speaker simultaneously in the same location. When a loud speaker is cut off, the relay substitutes a load resistor, thereby maintaining proper impedanse relations and preventing volume variation in other associated speakers. Where additional speaker capacity is desired, suitable amplifiers having high input impedance such as the Western Electric 94C may be connected in parallel with the existing speaker circuits.

The first model of the type 23 speech input equipment was the 23-A. The type 23-B speech input equipment as herein described is the same as the type 23-A in appearance, the only difference being in the arrangement of the controls on the panel. Some of the switching keys and mixer controls have been changed to different locations on the panel to afford a greater convenience of operation.

Space does not permit a complete description of the console speech equipment available from other manufacturers. However, we shall designate the model numbers of the apparatus so that the student may write directly to the manufacturer in case he desires additional information. The following speech input consoles are available: Model 12-H from the Collins Manufacturing Company, Cedar Rapids, Iowa; Model 20-B from the Gates Radio and Supply Company, Quincy, Illinois; Studio Control Desk Model 80-A from the RCA Manufacturing Company, Camden, New Jersey.

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SCHOOLS
INC.

POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 4

BROADCAST STATION PERSONNEL

LESSON NO. 5

A NEW NATION

........and a new era of progress.

Perhaps you have often wondered why it was that such great progress was made in science and mechanics following the discovery of America.

For countless thousands of years, the world existed without such modern conveniences as the modern steamship, the railroad train, the automobile, radio, and many other things to which we have become accustomed. Yet shortly after the discovery of America, the world entered upon an amazing era of new developments that completely revolutionized commerce and life. And for some reason, the majority of these discoveries originated within the boundaries of our own nation. Many, many times the question has been asked, 'Why?'

The answer to this question seems to be logical and has a direct bearing upon your personal success. First of all, the people who came to America in the pioneer days, were people who had been under restraint in the countries they had left. They could not worship as they wanted. They had beliefs that conflicted with those of imperialistic rulers. Because of the restraint under which they lived, their minds could not function freely. However, this condition was changed completely upon their arrival in America. They could think and do as they saw fit, so long as they did not break the law. They were inspired to greater efforts by the thought that their future depended upon their own efforts. And, having been dissatisfied with the lives they had left behind, they set forth to create a new and better nation of their own. That their efforts were rewarded with success is proved conclusively by the historical events that followed.

Your future, also, depends upon your efforts...NOW! The more time you devote to your studies, the better equipped you will be to accomplish greater and more profitable deeds in the days to come.

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Lesson Five

BROADCAST STATION PERSONNEL

"When you first start working in a radio broadcasting station, you will find yourself in an entirely new environment. As an operator, you will have technical duties to perform; however, as an employee of the radio station, you will be expected to know many things of a non-technical nature.

"In this lesson, I am going to tell you about the various departments and their activities in the average radio station. This information should enable you to adapt yourself quickly to the duties that will be assigned to you when you enter the radio broadcasting field."

1. STANDARDS OF PRACTICE. Upon securing employment at a broadcasting station, the employee will always be informed of the standards of practice as followed in the various departments. These will consist of rules and regulations as set forth by the president or general manager of the organization. The new employee is expected to familiarize himself thoroughly with the rules governing the operation of the department in which he has been employed and is also expected to be sufficiently familiar with the rules and regulations governing the operation of other departments so that he can extend the cooperation that is so essential for the efficient functioning of any organization.

The standards of practice as set forth by each broadcast station will differ from those established by other broadcast stations, Even though all commercial broadcast stations are engaged in the same type of business, the departments that are set up and the authority and privileges granted the personnel will vary because of the differences in managerial opinion. The general policy of the station will also be a governing factor as to the standards of practice that are followed. It is to be expected that the larger stations will establish a more elaborate technical and non-technical personnel. More departments are needed and more employees are required in order to efficiently handle the greater volume of business. It is not possible to set up a steadfast example to illustrate the departmental construction of a broadcast station; however, in the following discussion, we shall attempt to describe an average station in sufficient detail to enlighten the student on this subject. Every technical operator should be acquainted with the other divisions of the organization in which he is employed so that he may extend his cooperation and discharge his duties efficiently, thereby making himself a more valuable man.

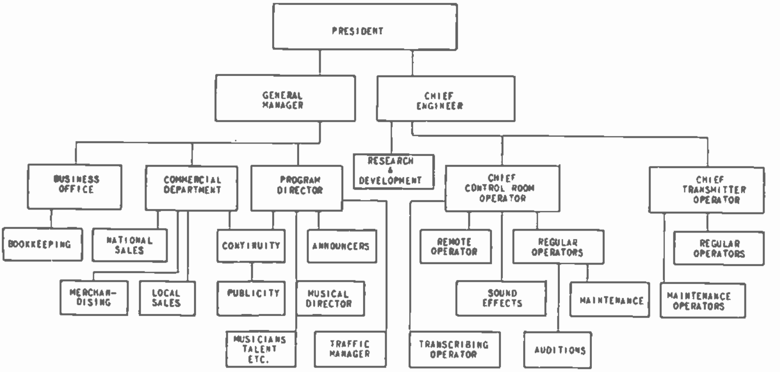

Fig.1 Block diagram of the personnel in the average radio station.

2. NON-TECHNICAL PERSONNEL. Fig. 1 shows a block diagram of the departments and personnel as employed in an average radio station. Let us briefly discuss each of those branches on the non-technical side.

(A) General Manager. For the most part, the activities of the general manager consist of making certain that all departments operate smoothly in selling, preparing, and producing radio programs. He has the entire non-technical staff of the station under his supervision and all problems which cannot be satisfactorily handled in the individual departments are referred to him for his advice or correction. In some cases, the general manager may be required to deal with problems in the technical department, however, his activities are generally confined to the program and sales departments.

(B) Program Director. The program director is the head of the program department where the radio programs to be broadcast are conceived and produced. His job is to supervise talent programs, continuity publicity, etc. The program director works in close cooperation with the sales manager, the business office and the chief engineer, since only a complete cooperation of these departments will make it possible to carry on the business of broadcasting in a successful and profitable manner. The program director usually has full authority for hiring and discharging employees in the program department, including in part the announcers, musicians, writers, etc. Since he is directly responsible for the programs that are broadcast over the station, it is necessary that he be intimately familiar with each item listed on the daily program schedule. When new programs or new talent are to be tested (auditioned), the program director must personally listen to the audition

or assign the duty to an assistant who in turn reports to him.

(C) Announcer. We are all familiar with the duties of a radio announcer. Usually one member of the announcing staff is appointed chief announcer and in this capacity he assigns the programs and working hours to the other announcers on the staff. In most cases, one of the announcers is assigned specifically to news broadcasting. It will then be his job to edit and prepare all of the news copy that is to be broadcast.

(D) Continuity. The writers who prepare the continuity or script to be used on the air compose the continuity department. This department may consist of from one to six persons, depending upon the size and policy of the station. Commercial programs and spot announcements must be well-written, clear, and forceful. This is the job of the continuity department.

As well as preparing the copy for commercial programs, the continuity department also writes many sustaining or non-commercial shows, such as dramatic skits, promotional material, etc. There is usually a continuity chief who distributes the work to his subordinates. He must be certain at all times that nothing objective or inaccurate goes on the air.

(E) Publicity. If the station's staff is small, one continuity writer may be assigned to handle all stations publicity, otherwise a special publicity department is created which confines its activities to that single purpose. Publicity means advertising the radio station itself in newspapers, magazines and radio trade journals, such as Broadcasting, Radio Daily, or Variety. Publicity may also mean advertising by means of promotional stunts, maintaining a booth at some civic enterprise, or in general, any activity which will keep the station and the programs of the station before the public eye. Often the publicity department will take care of bringing "big name" stars and prominent visitors before the station's microphone.

(F) Musical Director. The musical director of a radio station is invariably some one who has had considerable education in music. Frequently, the musical director of a small station is the staff pianist. The musical director is in charge of all the musical programs, as well as the music library, which consists of records, transcriptions, and sheet music. Also, the musical director is generally responsible for "clearing music" from ASCAP, a national organization.[1] If the station employs a staff orchestra, the musical director is in charge of that group; in fact, he might be called the musical program director. In some stations the musical director assists the program director on auditions, since so many of these are vocal or instrumental.

(G) Traffic Manager. The traffic manager of a radio station is the person to whom the mechanical work of the program staff is entrusted. His job generally consists of scheduling programs and compiling the continuity into a form to insure that it will be kept in chronological order by the announcers. The traffic man-

[1] The ASCAP organization will be described in detail in a later portion of this lesson.

ager's work must necessarily be closely allied to that of the commercial or sales department, in order that the contracted number of programs or spot annouuncements will be given to the sponsors.

(H) Commercial Department. The commercial department is ordinarily divided into two main groups, one of them handling the local sales and the other group in charge of the national sales. The national sales are nearly always handled through the station's national representative or through one of the national advertising agencies who handle the accounts for large manufacturers.

The number of local salesman employed by a radio station depends upon the station's size, it's scope and the locality in which it operates. In the larger cities most of the local advertising, as well as the national advertising, is brought directly to the station through a special advertising agency. In the smaller communities, however, and even in some large cities, the local salesman contact the business firms directly to solicit the advertising,

(I) Merchandising Department. The merchandising department may be contained as a part of the publicity or sales departments on some stations. Its job is to collect data and facts for the sponsors of commercial programs in order to provide definite proof that the programs being broadcast are effectively selling the sponsor's product. The various contests wherein prizes are offered by the sponsors are good examples of how the merchandising department collects its data. Also, programs on which box tops, cartons or bag fronts are requested serve to supply the same information. Those persons employed on a radio station who compile data of this kind are generally classified as employees of the merchandising department.

The importance of an efficient merchandising department to the welfare of a successful radio station cannot be disregarded. This department is largely responsible for the effectiveness of sponsored programs toward selling the sponsor's product. It promotes advertising schemes to gain listeners for the program, such as distributing placards, placing ads in local newspapers, and announcing the program with large signs in public places. All this serves to sell the public on the radio program, with both the station and the sponsor benefitting therefrom. The extensive advertising in filling stations to promote Skelly's "Court of Missing Heirs" is a good example.

Other functions of the merchandising department include: To collect territorial retail sales data; survey the type of audience the station reaches; and to determine the number of people, homes, autos, radio sets, etc., in the primary coverage area. These facts assembled are used by the sales department when attempting to convince national manufacturers of the value of using that station as an outlet for radio advertising in the locality covered. Competition between radio stations for national business demands that information of this nature be made available to the prospective sponsor.

In connection with the sales and merchandising departments, let us illustrate how a sponsored commercial program is usually built.

A salesman, we will say, contacts a department store executive and convinces him that radio advertising will help his sales and increase his business. The salesman approaches his client with a good idea as to the class of people that the buyer wishes to reach; that is, sport fans, housewives, farmers, children, etc. When he has sold the client on the idea of advertising, he then listens to any suggestion the buyer might have as to the type of program he prefers. If the client has no suggestions to offer, the salesman acquaints him with a number of the existing programs available which will reach the type of audience the advertiser wishes to appeal to. If none of these programs satisfy the sponsor, the salesman returns to the station and confers with the program director, and other members of the staff in an attempt to build the type of radio program that will suit the advertiser. When a decision is reached and the program is worked up into satisfactory form, the sponsor is invited to the station and is given an audition of the program. If he wishes to make any changes in the program or if he is entirely dissatisfied with the idea, the program director then works with the commercial manager until a program is built which does suit the sponsor's fancy.

In those stations where transcribing facilities are available, the program idea may be recorded on a transcription, then the salesman with his portable turntable, amplifier and loud speaker, calls on the prospective advertiser. He auditions the program for the sponsor in his own office, thus eliminating the inconvenience of asking the sponsor to make a special visit to the radio station.

New ideas for commercial programs are in constant demand at any radio station. Ideas are the "life's blood" of a station's commercial success. This has been considered so important by some stations that the commercial manager provides a special box in which all staff members are invited to deposit their original ideas or suggestions for radio programs.

In some radio stations, a new method of programming has been adopted, known as the "planning board" method. Under this system, there is no program director, but a "planning board", consisting of a staff member from each department, has a meeting about once a week to decide any questions concerning the program schedule which might arise. In this case, of course, there must be some one appointed to listen to auditions; however, all new talent, new programs, or new policies of the department must be approved by the planning board.

(J) Business Office. The business office has charge of the bookkeeping and financial side of the broadcast station's operations. The business office of a radio station is operated the same as the bookkeeping, auditing, and credit departments of other business firms. An intricate system of bookkeeping is required since the accounts of all the advertisers doing business with the station must be kept, in addition to the station's own expenditures and revenue.

3. TECHNICAL PERSONNEL.

(A) Chief Engineer. The chief engineer of a radio station is generally in charge of all engineers, operators, equipment, etc.

associated with the technical operation of the station. The chief engineer's duties coincide in the technical department to those of the general manager on the commercial side of the station. The chief engineer is expected to keep his department functioning smoothly and operating with the greatest efficiency. His primary objectives are to make certain that all the equipment necessary for broadcasting the radio programs is kept in good condition and that there are no unnecessary interruptions or failure in the equipment's operation. Both the transmitter and the control room are under the jurisdiction of the chief engineer; he is also expected to work with the program and commercial departments to insure the quality of the programs.

(B) Chief Control Room Operator. The control room engineer designated as the chief operator has charge of all the audio frequency equipment in the control room. He is also in charge of the control room operators. He is expected to supervise the technical activities on the control panel, maintenance of the equipment, sound effects, transcribing, remote control broadcasts, etc.

(C) Control Room Operators. The regular control room operators are in charge of the speech input equipment. They have the responsibility of making certain that the programs originate smoothly and that no unnecessary breaks occur because of technical deficiencies. The working shifts of the regular operators are generally assigned by the chief operator.

In addition to his regular technical operation duties, the control room operator is expected to keep the control room neat and in good order. He is also expected to keep other employees of the station out of the control room unless they have specific business therein. It is impossible for any person operating the controls in a radio station to devote the utmost attention to his work if the room is filled with outsiders. Their conversation is certain to distract his attention. Silence and absence of confusion are absolutely essential in the "nerve center of a radio station", the control room. The various duties of a control room operator which have to do with other departments in a radio station will be taken up in a later paragraph.

(D) Remote Operator. The remote operators are entrusted with the broadcasts which emanate from outside points, such as ball parks, dance halls, auditoriums, churches, etc. The remote operator is expected to make certain that his equipment is always in good condition. He is generally supplied with a daily schedule showing the place and time of the remote broadcasts he is to cover. On stations which schedule a number of daily remote programs, the remote staff consists of several engineers.

(E) Sound Effects. Most all radio stations employ a sound effects man who may or may not be a technical engineer. His work leads him to direct association with the technical department and even though he is not trained technically, he still must possess a certain amount of ingenuity in order to efficiently fulfill his duties. A sound effects man should possess considerable mechanical knowledge in order that he may construct and maintain the equipment which he is required to use. Some of the sound effects used in

radio stations for local programs are recorded. These recordings are played at the proper time by the sound effects man or possibly by the regular control room operator. It is extremely essential that these recorded sound effects be "dubbed" into the program continuity accurately and without pause or interruption.

(F) Maintenance of Equipment. The chief control room operator generally assigns the regular operators to a definite maintenance schedule. The maintenance schedule will include cleaning the attenuators in the mixer panel, cleaning and adjusting the points on all jacks in the jack panel, checking all of the amplifiers for proper operation, keeping all of the equipment clean inside and outside, lubricating turntable motors, etc.

The maintenance of the remote equipment is usually left under the direct supervision of the remote engineers.

(G) Auditions. One or more operators will be in charge of auditions. They will handle all except the important commercial auditions, which may be handled by the chief control room operator, or the chief engineer. Most stations have a specific time on a certain day set aside for general auditions; that is, for trying out aspiring announcers, singers, instrumentalists, etc.

In the case of program auditions for clients and station officials, or on a program rehearsal which is being monitored in the office of the program director or producer, an extra operator is needed in the control room. The control room engineers are notified ahead of time concerning these types of auditions and the chief operator makes sure that an operator is on hand for the audition at the specified time.

(H) Transcribing Operator. A recent innovation in many broadcast stations is the addition of transcribing facilities. The installation of this equipment makes it possible to record auditions, announcements, short programs, complete radio shows, special events, etc. After these have once been recorded, they may be played over the air at any convenient time or kept on file for future reference.

Frequently, it is impossible for a radio station to broadcast a certain program or event at a definite time because of outstanding contracts which cannot be broken. When an advertiser enters into contract with a radio station for a certain time, he is entitled to that time and his program listeners expect to hear the radio program at the designated hour. In many cases, an advertiser would lose a large percentage of his audience by changing the time of his program on the air. Now, if a special event should occur, such as a championship prize fight or an address by the President, the event is of interest to the general public and all radio stations want to broadcast it if possible. The station may ask the advertiser to relinquish his time in favor of the special broadcast; however, this constitutes a loss to both parties. Recently, it has become common practice to transcribe the special event as it came over the network, then rebroadcast it at a convenient time when no commercial program was scheduled. This method has proved to be financially beneficial to both the radio station and the advertiser.

Recordings of civic and other outstanding programs are now being kept by many stations for future use. Also, transcribing radio shows for the salesmen to assist them in selling a program to an advertiser is rapidly becoming popular.

This comparatively new department in a radio station requires efficient operators who are acquainted with the present-day art of "cutting" transcriptions. In most stations the transcription room is separate from the main control room so that the transcribing work may be carried on without interruption or inconvenience to either department.

(I) Chief Transmitter Operator. At the transmitter, the chief operator has the same position and authority as the chief operator in the control room. He is in charge of the transmitter and supervises the general work carried on. The regular operators will have daily shifts at the transmitter and they are required to keep a log on the transmitter's operation.

Maintenance operators are responsible for taking care of the equipment at the transmitter; this is a most important job.

(J) Research and Development. Many of the larger radio stations engage the services of research engineers in order to carry on experimentation and to develop equipment which will add to the efficiency of the technical operation of the station. The research department is "behind the scenes" and is not active in the daily operation of the station. In most cases, a special room near the control room or at the transmitter plant is set aside to provide a place for the research engineers to conduct their work. The results of work done by research departments in various radio stations has been largely responsible for the rapid advancements in the art of radio broadcasting.

4. TRANSCRIPTIONS. In some broadcast stations, the transcription and recording turntables are located in the control room while in other stations they are located in the studio. If in the control room, the transcriptions and recordings are played by the operator; if in the studio, the announcer on duty is generally expected to play them as he announces the program. Some broadcast stations employ a man who does nothing else except play the records and transcriptions. With this duty relieved from the operator and announcer, the program invariably runs smoother.

A transcription is an electrical reproduction which operates at 33⅓ r.p.m. It may be a reproduction of music, speech, or both. When a transcription is to be made, the production man assembles the talent for the script in the studio of a radio station or a transcription recording company and directs the performers through the rehearsals that are necessary to bring the show up to the desired standard. The microphones used for making a transcription are exactly the same as those used in broadcasting and the studio may be one at the broadcast station or a special studio located at the offices of the recording company. When a studio is designed especially for the transcription work, it is made a little more "live" than the average broadcast station studio.

The amplifying equipment used for making a transcription is the same as that employed in an ordinary speech input installation. Instead of the sound being fed from the output of the studio amplifier to the broadcast transmitter, it is transferred to a device on the transcribing machine known as the "cutting head". It is essential that a control operator be employed during the transcribing process in order to properly regulate the level of the audio energy fed into the cutting head. A special cutting needle, commonly called the "stylus", is mounted in the cutting head. As the audio frequency energy is fed into the cutting head, it will cause a mechanical, lateral motion of the stylus. These mechanical vibrations correspond exactly to the amplitude and frequency of the audio frequency sound waves set up by the artists in the studio. The motion cuts a vibrating groove in a revolving wax disc to correspond to the sound waves. If the transcription is to be used for an audition, as a test on the program for future reference only, or to be played back only once, it is cut on a type of disc which does not require further processing. This is called "instantaneous recording". On the other hand, if the program being transcribed is to be distributed to several stations, a sufficient number of "pressings" are made from the original. In the event of the latter, additional processing is necessary as will now be described.

After the initial wax disc is cut, it is immediately sent to a room where a special coating of silver is applied to protect it from oxidation and atmospheric changes. If allowed to take place, these changes would affect the quality of the final record. The silver deposit also acts as an electrical conductor which is necessary in the next step.

The silver coated wax disc is submerged in an electrolytic bath where a coating of nickel about .005 of an inch thick is applied by an electro-plating method. The wax disc is now taken out and placed in a copper electro-plating bath to strengthen the nickel. Upon being removed from this treatment, the metal deposit is removed from the wax and we have what is known as a "master disc".

The master disc is the reverse of the original wax in that instead of concave grooves it has convex ridges on the surface. The master disc is then put into a press for making a test pressing. The test pressing looks like an ordinary record except that it is much larger and thicker than the finished product.

If upon playing, the test record is found to be satisfactory, the master is then used to make a "mother disc". This process is exactly opposite that of making the master so upon completion, we have a metal "mother disc" from which any number of "stampers" can be made. The stamper, which is really a duplicate master, may then be used as a die for pressing the final transcription. Once the mother disc has been made, any number of stamper discs can be made. A stamper usually lasts for about 100 pressings before any degree of depreciation can take place that will affect the quality of the finished record.

The transcription discs are made from substances with various trade names, although basically they are of synthetic resins with variations in the compounding. Some manufacturers use vynal acetate or vinylite; some laminated shellac and some ordinary shellac. A synthetic resin disc has a much lower surface noise in addition to increased flexibility and a greater reduction in weight, without materially affecting the tensile strength of the record.

The stampers that have been made of the transcription are put into a huge hydraulic press and a sheet of pressing material is inserted in the press, then under a pressure of 80 to 150 tons the stamper is pressed into the material. As the pressman inserts the material, he includes the label so that it will be pressed into the material itself. The rough edges of the disc are then trimmed down and the transcription is ready for test and shipment.

There are several transcription companies which can furnish a complete library of all types of music and radio shows to broadcast stations for a certain fee. The better known of these companies are: World Broadcasting System; NBC Thesaurus; Associated Transcription Company; Standard Program Service; Titan Production Company; and C. P. MacGregor. Altogether, there are about 100 transcription companies in the United States from whom transcribed programs, musical selections, sound effects, news features, dramatic shows, etc. may be obtained.

When a broadcast station uses a transcription to present a dramatic serial, a comedy show, or a variety production, it is generally necessary to pay a royalty fee to the transcription company. These types of shows are usually 15 minutes long and are contained on a single 18-inch disc which revolves at 33⅓ r.p.m. C. P. MacGregor, Titan, and the World Broadcasting System are the outstanding producers of transcribed shows.

A transcription made for broadcast station use may be either vertical or lateral cut. A lateral cut transcription may be played with the same type of reproducing head that is used for playing phonograph records; however, vertical cut transcriptions require a special reproducing head, generally one with a diamond point needle. Recently the Western Electric Company has placed a "universal" reproducing head on the market. This unit employs a diamond point stylus and may be used for playing either lateral or vertical cut transcriptions.

The cost of the transcription service to a broadcast station varies with the size and quality of the library being purchased. In many cases, the cost will also be influenced by the station that is making the purchase; that is, some stations may be offered a more attractive price than others. Upon purchasing a library from a transcription company, the station not only receives the transcriptions themselves, but also several cross-index files. The initial cost also entitles the purchaser to replace a certain number of worn transcriptions each month. In addition, a special service is offered whereby the transcription company sends the station a certain number of written programs each week. These programs are timed to run either 15 or 30 minutes. This latter service is a great aid to the station's program department because it helps to fill a few hours in each daily schedule without the expenditure of effort on their part. The continuity prepared by the transcription company is given to the announcer, the transcriptions are taken from the files, and the program is put on the air, requiring no additional attention from the program department.

When a transcription has become worn, or if damaged in any way to render it unfit for use on the air, it should immediately be marked by the announcer or operator and the attention of the person in charge of transcriptions called to it. A report to the chief engineer giving the number and the title of the transcription damaged should be sufficient to see that it is reported to the proper person. If the transcription is merely worn, it will usually be replaced by the transcription company free of charge. If, however, the damage is due to an accident or carelessness, the station must pay a fee for a replacement. For this reason, every care should be taken to see that transcriptions are not placed where they may be damaged. Special filing cabinets are usually provided for this purpose.

New transcriptions are sent to the station each month to supplement the library, thus keeping it up-to-date.

Many sponsors of commercial programs choose to use the transcription services as a means of obtaining similar broadcasts over numerous stations without employing the facilities of network or chain broadcasting. These commercial transcriptions are generally made by local transcribing companies, then several copies are pressed from the original, and distributed to the stations over which the broadcasts are desired. They may consist of short commercial announcements, or, as in the case of "Chevrolet Musical Moments", a complete fifteen minute program of music and variety. These commercial transcriptions are always numbered and they must be watched carefully so that no program will be skipped or repeated.

Spot announcements are often transcribed by an advertising firm or an agency, then sent out to the various stations for broadcasting. These are generally 30 second or one minute announcements, and there are from three to six on a single disc. They are numbered and must be carefully checked by both the operator and the program department.

If at any time a faulty transcription comes to the operator's attention, it should be reported immediately and not used on the air unless absolutely necessary and has been approved by the program director.

5. RUNNING TRANSCRIPTIONS. Two turntables are always used when running a transcribed or recorded program. Fig. 2 shows how these tables should be arranged and the operator's position between them. The object of using two tables is to keep the program running smoothly; that is, to prevent a delay between an announcement and the starting of a musical selection. While the transcription on one table is playing, the operator places the next selection on the second turntable. It is then ready to start at the conclusion of the announcer's introduction or immediately following the selection that is now playing, if there is no intervening announcement. Most turntables are "universal", which means that they may be used to play either lateral or vertical cut discs at a speed of either 78

or $33\frac{1}{3}$ r.p.m. Convenient switches are provided to make the necessary changeovers.

5. CUEING TRANSCRIPTIONS AND RECORDS. "Cueing" a record or transcription means determining the time required to complete the number of turns through the blank grooves on the disc before the music or speech starts. This is done in order to present the record or transcription with a minimum of "dead air", yet allowing

Fig. 2 Positions of transcription turntables and operator for running a transcribed program.

enough turns to pass so that the proper speed will be attained before the music begins. If a transcription or record is started too near the beginning of the selection, it fails to gain $33\frac{1}{3}$ or 78 r.p.m. by the time the selection begins, the result is a "growl" or whine which sounds very badly when transmitted over the air. If the operator of the turntable carefully times the beginning of all records and transcriptions these difficulties can be prevented.

Many transcription companies mark the number of blank grooves preceding the starting point of the speech or music on the label of each disc, thus saving the operator considerable time and trouble. In most cases, however, this is not done, so the number of turns must be determined in the following manner: First, the transcription is placed on the turntable, then the needle in the reproducing head is placed at the beginning of the grooves. Some transcriptions are cut so as to start from the inside, while others are cut to start at the outside, so be sure to place the needle accordingly. With the needle in the first groove, the motor driving the turntable is turned on and the disc is permitted to revolve while the operator listens for the starting of the selection. A special amplifier with headphones may be used to assist the operator in locating the start of the speech or music. However, if an amplifier and headphones are not supplied, it is possible to listen closely and the needle's vibrations may be heard directly from the record. As soon as the starting point of the selection is determined, the operator stops the transcription from revolving by placing his hand on it. The motor driving the turntable is then turned off, the transcription being held until the table stops revolving. Without disturbing the position of the reproducing head, the disc is slowly revolved in a backward direction about 1½ turns. The transcription is then "cued" and ready to be played. Fig. 3 shows the transcription turntable in the studios of radio station KMBC.

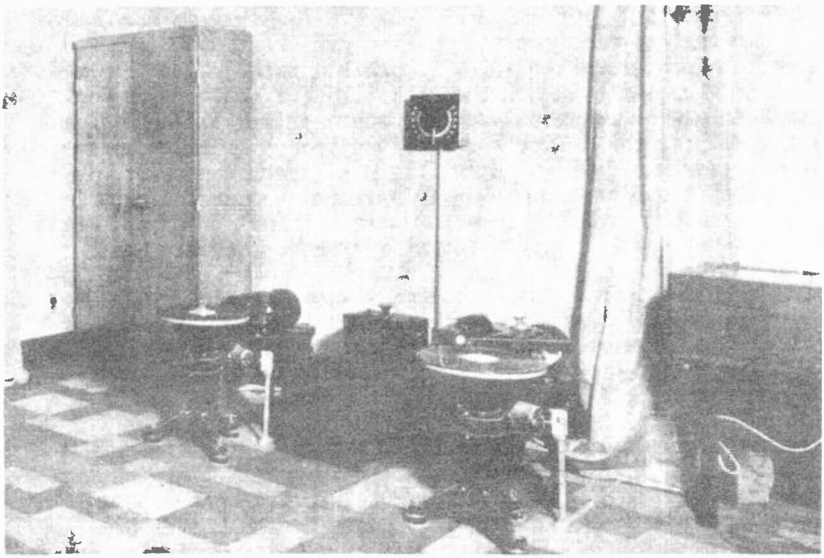

Fig. 3 Transcription turntables at radio station KMBC.

In the procedure outlined above, it was necessary to revolve the transcription disc backwards while the needle was resting in the groove. It should be understood that this is permitted only when a diamond point needle or a vertical reproducing head is employed. On most of the lateral reproducing heads, the needle is set in the chuck at an angle and will pierce through the side walls and bottom of the groove if the disc is turned backward while the needle is in position.

When the "cued" transcription is to be played, the operator starts the motor on the turntable. Upon completing the 1½ revolutions, the disc is up to proper speed and the selection starts without distortion of the speech or music. If the turntable is not of the type which gains speed rapidly, the operator generally starts the motor ahead of time, then holds the disc with his hand to keep it from revolving with the turntable. Sufficient pressure is not placed on the disc to slow the turntable down below normal speed, but still enough pressure is exerted to hold the disc stationary. At the proper time, the operator removes his hand from the disc and the selection begins after the disc has completed one or two turns.

Practically the same method may be used to cue recordings which revolve at 78 r.p.m. It is best to cue the records on a recorded program; however, some stations do not follow this policy. When cueing a recording, the music may be heard more distinctly if a piece of ordinary writing paper is placed between the needle and the record. Lay the paper flat on the record, then put the needle down and you will be able to hear easily when the musical selection begins. A speed of 33⅓ r.p.m. is more quickly obtained by a turntable than a speed of 78 r.p.m.; although there are generally more blank grooves on a transcription than on a record.

Turntables which operate at two different speeds will always have a changeover switch which is plainly marked "33⅓" on one side and "78" when switched to the opposite position. Before starting a transcribed or recorded program, make certain that you have the switch set for the proper speed. Even though it is very easy for the operator to fail to make this changeover when switching programs, it is one that is equally serious and inexcusable. By all means, such an error should never be made twice by the same operator during his length of employment at a broadcasting station.

7. ASCAP. This is an odd name with which everyone around a radio station quickly becomes familiar. The title is an abbreviation of the American Society of Composers, Authors and Publishers. The organization has been established for the protection of music composers and publishers. While this may seem to have little effect on the duties performed by a control room operator, it still plays a very important part in broadcasting. All of the music that is played over a radio station should be "cleared" by the program department before it is ever allowed to appear on the program schedule. However, an occasional mishap may occur in the program department which results in restricted music being scheduled for production on one of the daily programs. In this case, the operator in the control room should be sufficiently familiar with the general plan and purpose of the ASCAP organization so that he may call the oversight to the attention of the program department.

In order that a royalty shall be paid to all song writers and publishers who are members of the ASCAP organization, all broadcast stations are required to pay a certain annual license fee for permission to broadcast any of the music belonging to that organization. Since this music includes the majority of all music published, most stations pay the fee in order to enjoy the privilege. The ASCAP organization places certain selections, usually musical comedy or motion picture song hits, on what is called a "restricted list" to guard against too frequent playing over the air. This would kill the sheet music sales value of the selection, thereby decreasing the revenue to the composer and publisher. The restricted list is published four times a year, and copies of it are sent to all stations belonging to ASCAP. The additions to and removals from the list which are necessary during the intervening three month periods, are sent by mail to all broadcast stations. Each station is expected to correct the lists on hand, thus keeping them always up to date. Songs appearing on the restricted list cannot be played without special permission of the society. If they are played without permission, the station thus offending is subject to a fine of $250.00 for each violation. Should a restricted selection get on the air without permission, it should immediately be cut off by the operator, if possible, before eight measures or bars of the tune have been broadcast. If a restricted number is taken off the air before eight bars have been played, the fine will not be levied against the management of the station.

A copy of the restricted list, together with its additions and deletions is usually kept within reach of the operator on the control board so that he may look up a number at any time. All the announcers on the station should be very familiar with this list, as well as all members of the program department. It is impossible for any one person to memorize the entire list since it generally contains from 1,000 to 2,000 songs. However, an acquaintance with the more popular ones will generally prove helpful to all those associated with the program and technical departments of the station. When permission is received to play a restricted number, a notice of this permission should be posted in the control room so that the selection will not be taken off the air by the operator. Occasionally, selections on the list will be marked "restricted for commercial use only", which means that no permission is necessary from the society to play it on a sustaining or non-commercial program.

Only rarely do "slip-ups" regarding restricted music occur on the larger net work stations, but on small stations, everyone's cooperation is needed to avoid this disastrous occurrence. Especially is this true regarding the broadcasts of local bands, who generally make no attempt whatsoever to keep well-posted on the restricted numbers that are used. Ordinarily, the program department requires that each artist and each band appearing on the station submit a complete list of all the numbers they intend to use. These lists are then carefully checked and all restricted music is either discarded from the program or written permission is obtained from the ASCAP organization before the number is played on the air.

7. F.C.C. RULES AND REGULATIONS REGARDING RADIO PRODUCTION. Upon securing a position as radio operator, either in the control room or at the transmitter, the new employee should immediately acquaint himself with all the FCC rules and regulations regarding the operation of the equipment with which he is entrusted. The complete set of rules and regulations can always be secured from the chief engineer of the station. In this lesson, we shall specify a few of the more important ones in order that the student will

be familiar with them when he secures a position.

3.71 - MINIMUM OPERATING SCHEDULE. Except Sundays, the licensee of each standard broadcast station shall maintain a minimum operating schedule of two-thirds of the total hours that it is authorized to operate between 6 AM and 6 PM, local standard time, and two-thirds of the total hours it is authorized to operate between 6 PM and midnight, local standard time, except that in an emergency, when, due to causes beyond the control of the licensee, it becomes impossible to continue operating, the station may cease operation for a period of not to exceed 10 days, provided that the Commission and the Inspector in Charge shall be notified in writing immediately after the emergency develops.

3.401 - 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 Secs. 2.51 and 2.52)

3.402 - 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 Sec. 2.53)

3.403 - 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 nowise interfere with the proper operation of the standard broadcast transmitter.

3.404 - 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 each 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.

3.405 - 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.

3.406 - 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 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.

3.407 - 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".

3.408 - REBROADCAST

(a) The term "rebroadcast" means reception by radio of the program of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.

(b) The licensee of a standard or high-frequency broadcast station may without further authority of the Commission, rebroadcast the program of a United States standard or high-frequency 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.

(c) The licensee of a standard or high-frequency broadcast station may, without further authority of the Commission, rebroadcast on a non-commercial basis a non-commercial program of an international 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.

(d) 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.

(e) 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 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.

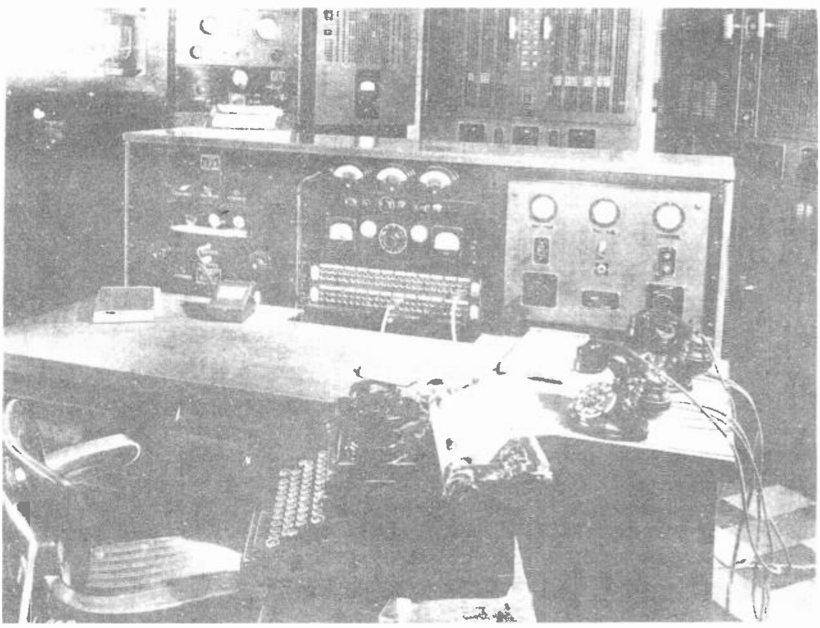

Fig.4 Control log at transmitter plant of KMBC. Note the operating log sheet in the typewriter.

The operating log at the transmitter must conform with the requirements as specified by the FCC. In addition to these requirements, the transmitter log is expanded to keep an accurate account of many additional facts concerning the operation of the transmitting equipment itself and duplicate information regarding the time and nature of the programs broadcast. The transmitter log will always show a complete account of every detail concerning the transmitter's operation and the programs being broadcast. Fig. 4 shows the control desk at the transmitting plant of KMBC. The log is kept on the typewriter.

A daily program schedule is given to the operator in the control room by the program department in order that he will know the exact nature and origination of each program that is to be broadcast during the day. Ordinarily these program schedules are made up some time in advance (generally one week) and alterations are made by the program department when necessary. Unless otherwise informed, the control room operator is to assume that the submitted program schedule is correct, so he should proceed to make the necessary microphone setups and arrangement of his equipment to handle the programs as they appear consecutively on his program schedule. Should an interruption or break occur due to an error on the program schedule, the operator is not held responsible, but instead the program department is totally to blame.

Many abbreviations will appear on the program schedule. Abbreviations will also be used by the control room operator and transmitter operator in keeping their daily logs. The operators must be familiar with such abbreviations in order to interpret the meaning thereof. Some abbreviations used are personal concoctions of the management of the station; however, there are several in common use which should be immediately apparent to the operator. The important ones are given as follows:

TRS or ET ...... electrical transcription,
REC or R .... recorded,
NEMO or REM .... remote,
LOC or SP ...... live talent, studio program,
SPT or S. ANC .. spot announcement,
SUS or S .... sustaining,
COM or C .... commercial.

Commercial spot announcements and sponsored programs frequently appear on the program schedule in red print, whereas the sustaining or non-commercial programs appear in black print. Since the financial income of the station depends on the efficient production of commercial programs, the control room operator is expected to devote his utmost attention to them. The red print on the program schedule serves to impress their importance.

9. MICROPHONE PLACEMENT. Placement of a single microphone or several microphones for a studio broadcast is one of the important jobs of a control room operator. From his technical knowledge of microphones and the practical experience which he gains by working for a short while in certain studios, he should be in a

position to determine quickly where the microphones should be placed, how many of them should be used for certain types of programs, etc. Many stations leave the microphone placement entirely to the control room operator; however, some larger stations employ a studio director who is sufficiently acquainted with the technicalities of microphone operation to qualify him for the job. An ear for music and a sense of showmanship are invaluable assets to enhance a person's ability in microphone placement.

During first attempts to make microphone setups, solicit cooperation from members of the station's musical staff to insure that the best results will be obtained. For instance, in setting up an orchestra, it may be necessary to experiment with several microphone arrangements. If the musical director or orchestra leader listens to the various setups with you, it will be much easier to obtain the desired balance than if you attempted to pass the final judgment yourself. Remember, the music of a soloist, choir, or orchestra may be distorted so badly by faulty microphone placement that half of the tone quality is lost or buried because of the lack of balance. Use one microphone whenever possible, then take time to experiment until you get everything the one microphone can possible deliver.

Microphone placement depends largely upon the acoustics of the studio in which the program is originating and the type of microphone employed. Also, it may be desired to obtain certain abnormal effects which are slightly out of balance with natural quality. In any event, experimentation is an invaluable aid, and every control room operator should attempt to acquire a general knowledge of the best working positions for the microphones in the studios where he is employed. The existing acoustic conditions must be accepted since it is impractical to change the reverberation time or general layout of a studio each time a different type of program is to be broadcast.

Satisfactory reproduction can usually be secured if the following general rules are taken into consideration: Microphones should be placed as far as possible from any surface which reflects sound waves readily. These surfaces will include the glass windows in the studio, untreated walls, large metallic objects (such as air-conditioning machines), a wooden floor, a group of folding chairs, sound effects equipment, tables, bookcases, filing cabinets, etc. Some of these objects are never placed in the average radio studio; however, if such a situation does exist, the microphone should be placed at least three feet from these large objects. The windows in most broadcast studios are slanted either toward the floor or toward the ceiling so that sound waves striking them will be reflected away from the microphone itself. When sound is radiated from a given point (the artist or musical instrument) its intensity decreases as the square of the distance from the source. Thus, if the distance between the sound source and reflector is increased, then the reflected sound as returned to the microphone will be decreased.

Adjustment of the proper distance between the sound source and the microphone is also an important factor in obtaining high-quality reproduction. The type of microphone being used will be very instrumental in this respect, as well as whether the sound source consists of voice or music. A few of the reflected sound waves from the studio walls, floors, windows, etc. should reach the microphone in order that the musical rendition or speech will sound natural to the ear. This means that all studios should be "live" to a certain extent and not completely "deadened" by the use of too much sound absorbent material. If all reflected waves are completely absorbed and none reach the microphone, the resultant sound as reproduced over a loudspeaker will sound very dead to the listener. The resultant characteristic of the microphone output can be influenced by experimentation with the relative distances between the sound source and the reflecting surfaces. Decreasing the distance between the microphone and the sound source increases the proportion of the original sound to the reflected sound, and vice versa. Quite frequently, proper microphone placement affords the only solution to the problem of poor acoustics in a radio studio or on a remote broadcast.

Fig.5 Main studio at KMBC. These walls are scientifically treated with acoustic material.

Adjusting studio acoustics is a highly specialized field. Some of the larger studios are arranged so that the acoustics may be varied quickly and easily by pulling drapes or sliding panels in order to provide the effect desired to different types of programs. When extremely technical problems arise in acoustical work, the operator should suggest to the station management that he engage the services of specialized acoustical engineers. These men have made a prolonged study in this field and are obviously in a much better position to obtain the desired results at a minimum expense than the radio operator who has confined his activities to the technical and the practical study of radio practice. Fig. 5 shows the main studio of KMBC, which has been acoustically treated with highly efficient sound material.

It has been shown in a previous lesson that the frequency characteristics of any diaphragm type of microphone are dependent upon the relative positions of the microphone and the source of the sound. When the sound waves approach at right angles to the plane of the microphone diaphragm, a uniform response over the complete range might be obtained. However, if the sounds approach from any other point, it will be found that the response falls off at the higher audio frequencies when the sound source is at an angle with respect to the microphone diaphragm. The majority of

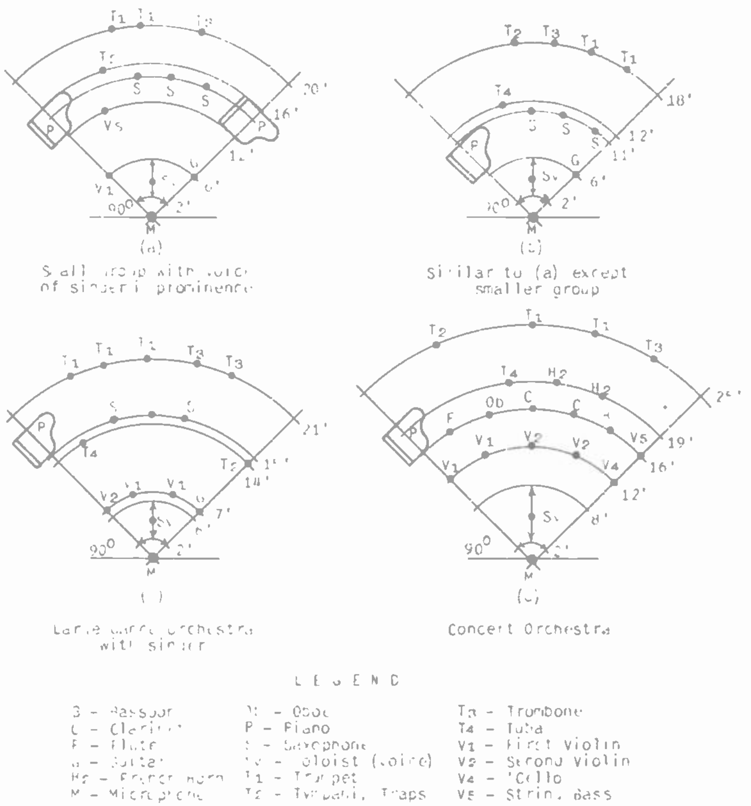

Fig.6 Typical arrangements of orchestral groups using a single microphone.

musical instruments depend for their quality upon the presence of overtones or harmonics; hence, if these overtones are lost or reduced, the quality will be changed materially.

Many factors are involved in securing the proper placement of vocal sound sources or musical instruments before a pressure or diaphragm type microphone. After certain rules have been set up, they still serve as only a guide. Most satisfactory results are achieved by studying the type of program and the microphone characteristics, then actually setting up the preferred arrangement in a studio. A final check on proper microphone placement should be made by a series of listening tests over a high-fidelity speaker and monitoring system by one who has an ear trained for music or for the naturalness of sound.

In Fig. 6 several arrangements are shown for orchestral groups arranged for broadcasting over a single diaphragm type, pressure operated microphone such as the carbon, condenser, inductor, dynamic, or crystal. The characteristics of these types of microphones permit the placement of musical instruments within an area enclosed by an angle of about 45 degrees to either side of the microphone face. When using these types of microphones, the sound source, speaker, announcer, or musical instrument should not be placed closer than one foot from the face of the microphone.

Velocity microphones have bi-directional characteristics and are advantageous in that the performers can be grouped on both sides of the instrument in a manner as shown in Fig. 7. Velocity

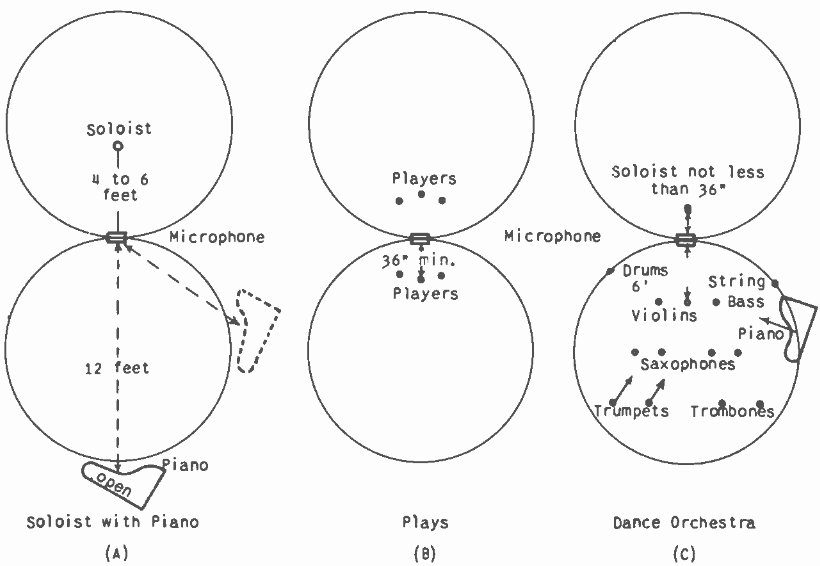

Fig.7 Arrangements for using a bi-directional velocity microphone.

operated microphones have uniform frequency response characteristics in two directions. This is a decided advantage in that the intensity of some instruments may be decreased without discriminating against their higher frequencies simply by placing them at a larger angle with respect to the microphone axis.

10. SPECIALIZED CONSULTATION SERVICE. When extremely specialized problems arise in the radio broadcasting field, it is advisable for the average radio operator or engineer to solicit the advice and consultation of firms who specialize in the solution of these problems. Throughout the United States, especially in the eastern section, there are numerous radio engineering firms who specialize in certain fields of work. These men are in the business of offering their services to radio stations so as to assist them in obtaining the very best results with their present equipment or on proposed changes which they desire to make. Since these firms are constantly encountering highly specialized problems in the field, it is always wise to engage their services, even though the engineering staff of the radio station may feel capable of working out some of the more difficult problems which occasionally arise.

Some of the services available from these consulting radio engineering firms include: Making field intensity surveys; installing directional antenna equipment; designing transmitter plants; determining the best location for broadcast antennas; installing and adjusting new transmitting equipment; designing studio apparatus, switching, and relay systems; adjusting antenna reflectors; etc. One of the outstanding firms organized to provide service to the field of radio broadcasting is the Jansky & Bailey Co., located in the National Press Bldg., Washington, D.C.

For engineering consultation on studio acoustic problems, the Johns-Manville Co., 22 E. 40th St., New York City, offers a very complete service. This company has been manufacturers of sound and acoustic materials for several years and has completely engineered the studio construction of several broadcast stations.

11. NEWS SERVICES. News broadcasting has become one of the most outstanding public services offered by broadcast stations in the past few years. There are several agencies which supply the daily news to stations for broadcast purposes. The methods used by the agencies in preparing and submitting the news items vary considerably. For example, news available through the Christian Science Monitor is mailed to the radio stations daily. The United Press Service is generally sent to the radio stations over a special ticker tape; this makes it possible for the radio station to obtain the news events as they occur during the day and night. Some stations, especially those in small communities, obtain their news bulletins by employing a radio operator to copy the news items as they are transmitted by code over high-powered telegraph broadcast stations maintained by Hearst Radio, Inc., Press Wireless, Inc., and others. Major news services available to the radio broadcasting stations include: International News Service, Transradio Press Service, United Press, Christian Science Monitor, Press Radio Bureau, and Radio News Association.

Notes

(These extra pages are provided for your use in taking special notes)

Notes

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UNIT NO. 4

ANTENNAS

LESSON NO. 6

OLIVER HEAVISIDE

A detailed study of the transmission of radio waves is not complete without reference to the name Oliver Heaviside, for his electrical research and experimentation played an important role in the advancement of this phase of the radio industry. Although his work played an equally important part in telegraphy and telephony, he is perhaps better known for his theory which is widely accepted today in explaining the peculiar behavior of propagated radio waves.

Born in London on May 13, 1850, Heaviside was a contemporary of Thomas Edison, and like Edison, was hampered through life by deafness. He had only a common school education and was still quite young when he secured a position with the Great Northern Telegraph Company at Newcastle. However, increasing deafness caused him to retire from business in 1874. It was then, at his home in Devonshire, that he began the experimentation and research work which later made him famous.

Due to Heaviside's methods of mathematical calculation, which were unusual and unorthodox, he found it difficult to obtain recognition for his works, and practically impossible to get them published. The latter obstacle, he overcame by publishing them himself in 1892. In his mathematical work, he used a term which he called an "operator", and his methods were known as "Heaviside's Operational Calculus". The value of these methods have since been recognized, and today they have become widely adopted.

In his experimental work, Heaviside delved into the problems of duplex and multiplex telegraphy, electrostatic and electro-magnetic induction; and his theory on long-distance telephony was a prime factor in the development of this phase of communication.

Heaviside's most widely known contribution to radio was his theory on the presence of an ionized layer existing in the Earth's upper atmosphere, which prevents electrical waves from spreading into space. This has since become known as the "Heaviside Layer", and is sometimes referred to as the "Kennelly - Heaviside Layer", or the "ionosphere". Definite proof of the existence of the Heaviside Layer has been furnished by the "skip distance" effect of radio waves.

Heaviside died at Torquay on February 3, 1925, at the age of 75.

Determination like that possessed by Oliver Heaviside is often the deciding factor between fame and oblivion. He answered the challenge to his success, and today his name ranks among the leaders in his field.

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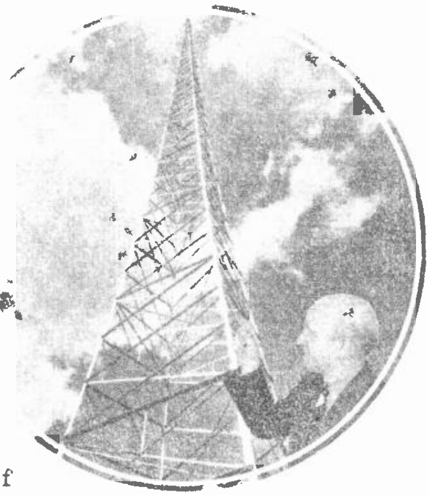
Lesson Six

ANTENNAS



"This lesson is devoted to a thorough study of the fundamental principles of antennas. No matter how efficiently a transmitter may be operated, it will not produce satisfactory results unless it is properly connected to a suitable antenna.

"Sometimes, students of radio are apt to make the study of antennas complicated and difficult; so when you study this lesson, keep an open mind and don't make something hard out of an easy subject. A complete training in radio requires a good working knowledge of antennas."

1. THE MECHANISM OF RADIATION. At this point the student should be familiar with the operation of a transmitter. The principles underlying the generation of R.F. waves have been explained in some detail in previous lessons. From his general knowledge of the subject, the student knows that after the R.F. energy has been amplified the desired amount, it is transferred to an antenna which radiates it into space. Just how the process of radiation occurs has been hinted at only vaguely. Now we are ready to consider in detail the design and operation of transmitting antennas.

An antenna may consist of one or more horizontal wires, a vertical tower, or an extensive array of towers with wires strung between them. In any event it is to be understood that an antenna is nothing more than an oscillatory circuit. True, it is considerably different in appearance from most oscillatory circuits with which we are familiar, yet fundamentally, it consists of nothing more than inductance, capacitance, and resistance. It will have a resonant frequency which is that frequency at which its inductive and capacitive reactances are equal. To produce an appreciable amount of antenna current, it is necessary that the antenna be excited with energy of its resonant frequency, or that the antenna be tuned so that it will be resonant at the frequency of the transmitter.

Let us first consider a simple oscillatory circuit such as shown in Fig. 1. Surrounding the coil is a magnetic field which varies in intensity and direction as the current through the coil alternates. Between the plates of the condenser there exists an electrostatic field. The magnetic field is confined closely to the space directly around the coil, likewise the electric field is practically non-existent except in the vicinity directly between the plates of the condenser. As has been explained in previous lessons, the energy in this oscillating system is being repeatedly changed from electromagnetic to electrostatic. As the current through the coil rises, it creates a magnetic field, and this field

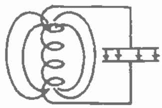


Fig.1 Closed oscillatory circuit.

represents a definite amount of energy. With a decreasing current, a collapse of the magnetic field occurs, and *all of the energy contained in the field is given back to the circuit*. In a like manner, the establishment of the electric field requires the expenditure of a certain amount of energy which is also returned to the circuit when the condenser discharges. A circuit of this kind is called a *closed oscillatory circuit*. Practically none of the energy escapes into the surrounding ether, but instead merely oscillates back and forth.

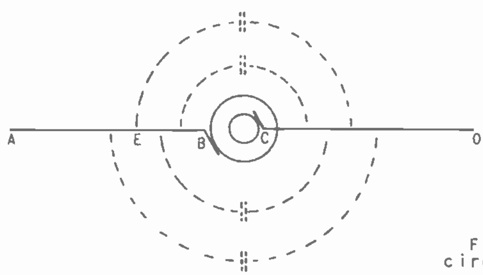
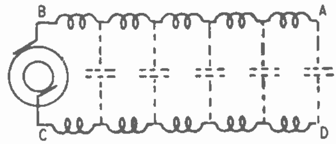


Fig.2 Open oscillatory circuit.

Now let us consider Fig. 2. This illustration shows an alternator to the terminals of which there is connected a straight wire. It is to be assumed that the alternator is capable of generating a voltage of radio frequency. The two wires extending from the alternator have some inductance and furthermore, each small length of the conductor AB will have a certain capacity to every small length of the wire CD. This capacity is not lumped as in the case of the closed oscillatory circuit, but rather, is distributed, and as a result, the total capacity between the two wires is of a very complicated nature. The function of the alternator is to charge one wire positively and the other negatively, and then to reverse the polarity of the charge. For example, to charge wire AB positively and CD negatively, electrons must be taken from AB and forced into CD. Thus, there is seen the necessity of having conductors capable of storing an appreciable amount of electric charge, or conductors with a reasonable amount of capacitance.

When the voltage of the alternator is at its peak, the greatest voltage difference will exist between the two wires, and the electric field between them will be maximum. Note, however, that this electrostatic field is not confined as in the case of an ordinary condenser, but that the electrostatic lines of force may extend outward for great distances from the two wires themselves. In fact, it may be proved that theoretically the field extends for an infinite distance in all directions.

Fig.3 Distributed inductance and capacity in an antenna system.



Naturally, there will be an alternating current flowing in the two wires to charge the capacity existing between them. This current will not, however, have the same value in all parts of the wires. Thus, there will be the largest current flowing at points B and C and no current will flow at points A and D. It is not hard to see why this is so, when it is realized that the current to charge all parts of the wires must flow past points B and C, whereas, since there is no capacity existing beyond points A and D, there will be no charging current flowing past these points. Past an

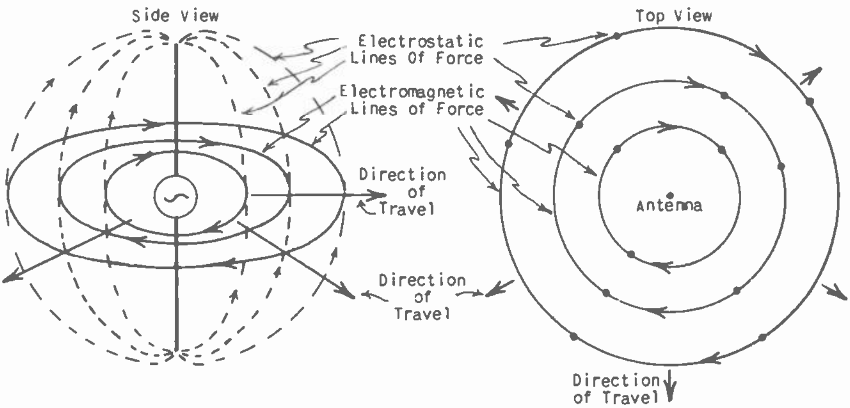


Fig.4 The fields existing about an open oscillatory circuit.

intermediate point such as E there will be some current flowing, although not as much as at point B, since the current flowing past point E will be that required to charge that part of the wire between points A and E. By redrawing the two wires so that they have the form shown in Fig. 3, where the various condensers drawn between the two represent the distributed capacity existing between them, it is easy to see that the greatest current will flow near the alternator, and that there will be no current flow at the open ends.

The production of this radio frequency alternating current in the two wires creates an electromagnetic field around them. This field, however, is not confined, but rather, extends outward for an infinite distance in all directions perpendicular to the two wires. Fig. 4 illustrates the magnetic and electric fields existing about the two wires. The solid lines represent the magnetic lines of force which consist of concentric circles surrounding the two wires. The dotted lines drawn from one wire to the other are the electrostatic lines of force which exist between the various parts of one wire and corresponding parts of the other. Realize that these two fields represent a considerable energy, and in the case of a simple oscillatory circuit, this energy is being continually returned to the circuit. An antenna, however, is not a simple oscillatory circuit; rather it is called an open oscillatory circuit in that its magnetic and electric fields are not confined, but extend outward for great distances.

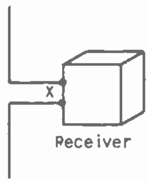
If we were to stop right here and explain nothing further about the fields surrounding the antenna, we would not have explained the process of radiation. The field which we have described is an induction field, and decreases in magnitude by the square of the distance away from the antenna. The electromagnetic and the electrostatic fields in this case would be 90 degrees out of phase, since the voltage developed between points A-D of Figs. 2 and 3 is produced by the current flowing in the wires BA and CD, and therefore reaches its maximum 90 degrees after the maximum current was started on its journey at points B and C.

The fields surrounding the antenna not only build up and collapse in synchronism with the changing current and voltage in the antenna wire, but these fields tend to expand in such a way as to completely fill the universe. This expanding process constitutes a movement of the field in all directions away from the source, which in this case is the antenna of Fig. 2. Since the field is moving away from the antenna, all of the energy which is stored in this field during the build up of current and voltage along the antenna wires cannot be returned to the antenna when the current and voltage collapse as would be the case in a completely closed oscillatory circuit having negligible loss. This loss of energy from the antenna due to the expanding field constitutes radiation. Since the radiation field consists of traveling waves whose circumferences are continually expanding, the intensity of the field decreases as the first power of the distance from the antenna. Furthermore, since the radiation field actually constitutes a power loss from the antenna, the magnetic and the electrostatic fields are in phase. The mathematical proofs of this, based upon Maxwell's equations, are beyond the scope of this lesson.

There are some other interesting concepts of the radiation field with which the student should become familiar. In Fig. 4, we notice that while the electrostatic lines of force about the wire were produced from one end of the wire to the other, the electromagnetic lines of force encircled the wire. Therefore, in all points of the field about the wire, the electrostatic and electromagnetic lines of force are perpendicular to each other. Furthermore, the radiation field is expanding away from the antenna wire itself and the directions of travel of the waves are therefore perpendicular to both the magnetic and electrostatic fields, as may be observed in Fig. 4. The combined effect of the expanding field about the wire plus its rapid oscillation in synchronism with the changing current and voltage in the wire produces traveling waves of electromagnetic and electrostatic flux which propagate away from the antenna with the speed of light, or 300,000,000 meters per second.

The voltage drop produced in the space about the antenna by the electrostatic lines of force is a measure of the field strength. For instance, if we could place a voltmeter across one meter of the ether and observe a reading of one volt, we should say that our field strength was 1 volt per meter. This is a very high field strength, usually produced only in the immediate vicinity of the transmitting tower. Normally, fields are measured in microvolts per meter or millivolts per meter, which are .000001 and .001 volt per meter respectively. The field strength measured in this manner would be exactly the same as the voltage induced in 1 meter of receiving antenna wire. This does not mean that if we have a receiving antenna such as Fig. 5, that a voltage of 1 volt would be delivered at the terminals for a field strength of 1 volt per meter. The voltage actually delivered at the receiver depends in a very complex way upon the impedance of the antenna, the impedance of the receiver, and the current distribution in the antenna. The actual means of measuring the field strength is best left to a later lesson.

Fig.5 Simple receiving antenna.



The field at the receiving antenna is the combined induction field and radiation field. Near the antenna the induction field is much stronger than the radiation field, but farther from the antenna, the radiation field is much the stronger. This follows from the fact that the strength of the induction field at any point is inversely proportional to the square of the distance away from the antenna, whereas the strength of the radiation field at any point is inversely proportional to the first power of the distance away from the antenna. For example, at 200 feet from the antenna, the induction field is only one-fourth as strong as it is at 100 feet; whereas the radiation field would be one-half as strong at 200 feet as at 100 feet.

It should, of course, be realized that the direction of the electric lines of force are at right angles to the direction of the magnetic lines of force and that both are at right angles to the direction of travel. This is true of both the induction and the radiation fields.

2. THE VOLTAGE AND CURRENT DISTRIBUTION OF AN ANTENNA. The following discussion will be comparatively simple, if we but remember that an antenna is nothing more than a special type of oscillatory circuit. Let us now consider Fig. 6, which shows a battery connected in a series oscillatory circuit. When the switch in this circuit is closed, a current will flow out of the battery to charge the condenser. As this current is rising, there will be created across the coil a voltage which tends to prevent the current from

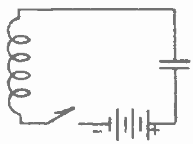


Fig.6 Series oscillatory circuit.

rising. This voltage will be of such polarity as to buck against the voltage of the battery. When the condenser has acquired a part of its charge, the charging current will begin to decrease, and the falling current in flowing through the coil will induce into the coil a voltage which tends to keep the current from falling. The polarity of this voltage will be such as to add to the voltage of the battery. As a result, the condenser charges to the voltage of the battery plus the voltage induced across the coil. The current now stops, but the condenser is charged to a greater voltage than that of the battery, and as a result, the condenser begins to discharge until it has the same voltage as the battery. As the discharge current begins to decrease, there is created across the coil a voltage which tends to

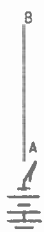
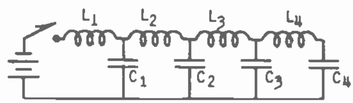


Fig.7 Charging a straight wire.

prevent the decrease, and the polarity of this voltage is the same as the voltage across the condenser. Thus, the condenser continues to discharge until its voltage is somewhat less than the battery voltage. There is, therefore, created in this circuit an oscillating current which is rapidly damped. The oscillations continue until the energy has been dissipated, at which time the voltage across the condenser is equal to the battery voltage. The peak voltage across the condenser during the first few oscillations may be much greater than the battery voltage.

In Fig. 7 there is illustrated a battery, one terminal of which is grounded, and the other terminal connected through a switch to a straight wire. The wire will have some inductance, and there will be a certain capacity existing between different parts of the wire and ground. When the switch is closed, a charging current will flow into the wire to charge the capacity between the wire and ground. Let us assume that the voltage of the battery is 100 volts. It might, then, be thought that the current merely continued until all parts of the wire were charged to a voltage of 100 volts with respect to ground. This, however, is untrue. The distributed inductance and capacity of the wire can be represented approximately by the circuit shown in Fig. 8. It is seen that the condenser C_1 will be charged to a greater voltage than that of the battery, because of the induced voltage across the coil L_1. Likewise, the condenser C_2 will be charged to a still higher voltage, because of the induced voltage across the coils L_1 and L_2. Finally, the condenser C_4 will be charged to the highest voltage, because the voltage charging it is the voltage of the battery plus the induced voltages of the coils L_1, L_2, L_3, and L_4.

Fig. 8 The circuit analogy for the charging current of a simple wire.



Now, the same principle applies to the charging of the straight wire shown in Fig. 7. Those parts of the wire near the battery will be charged to a voltage only slightly higher than the battery, whereas, the open end of the wire will have a voltage with respect to ground which is considerably greater than the voltage of the battery. Naturally, such a condition cannot continue to exist, and so, the excess charge present at the open end of the wire forces a current in the opposite direction back to the battery. This current will flow until the voltage between the open end of the wire and ground is somewhat less than the battery voltage, and then the wire will again take a charge, this process continuing for several cycles. It is apparent that the voltage wave travels up the wire from the battery until it reaches the open end and is then reflected back to the battery, successive reflections occurring until the energy in the system has been dissipated.

When an alternating voltage of high frequency is substituted for the battery, practically the same phenomenon is observed. The voltage wave travels out to the end of the line and is reflected back to the alternator, although if the inductance and capacity of the wire are correct to make it resonant at the frequency of the alternator, the reflected wave reaches the alternator at the exact moment that the alternator is reversing its polarity. Thus, the reflected wave is absorbed by the alternator, and the wire now takes a charge in the opposite direction. For each alternation executed by the alternator, there is one direct wave and one reflected wave. The effect of these two waves traveling along the wire in opposite directions is to create a standing wave along the conductor by cancellation in parts of the conductor and reinforcement in other parts of the conductor, depending upon the relative polarity of the two waves at the point considered.

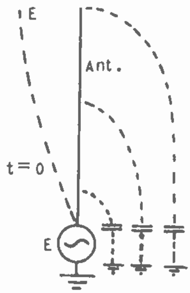


Fig.9 The initial voltage distribution along a charged wire.

Instead of expressing the resonant frequency of an antenna in kilocycles, it is customary to state its resonant wavelength in meters. As is well known, there is a very definite relationship between the wavelength and the frequency and when either one is known, the other can be found. In some cases, the electrical length of an antenna is the same as its actual physical length, although usually the electrical length is slightly greater than the physical length. This is due to the fact that the velocity of radio waves along a conductor is slightly less than their velocity in free space. For example, let us consider a half-wave antenna which is to operate on 20 meters. One-half of this is 10 meters, but the antenna would be cut to a length of approximately 9.5 meters so that it would be resonant at a frequency corresponding to 20 meters.

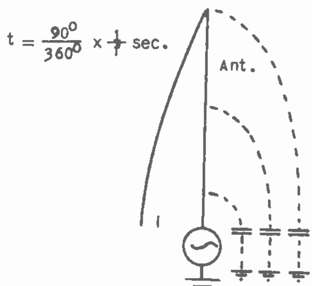


Fig.10 The distribution of charging current along a single wire.

To define further just what is meant by the wavelength of an antenna, we shall have to investigate the phenomenon of standing waves. The current passing any given point in the antenna at any instant is due to the combined result of the direct wave and the reflected wave. We shall first consider the quarter-wave antenna. At the instant that all of the various condensers representing the distributed capacity are fully charged, the current is zero, and the voltage distribution along the antenna is that illustrated in Fig. 9.

The dotted line drawn along the antenna indicates by its distance from the antenna the voltage existing at any point. Thus, the maximum voltage is present at the open end, and the voltage at the end

Fig.11 The current and voltage distribution during the charging of a straight wire.

nearest the alternator is merely the alternator voltage. The condensers begin to discharge, and at the instant that they are completely discharged, the current is maximum in the antenna. The voltage along the antenna is zero at every point, and the current has the distribution shown in Fig. 10, where the solid line indicates by its distance from the antenna the amount of current flowing past any point. Thus, Figs. 9 and 10 represent the conditions existing at two different instants separated by one-quarter of a cycle or 90 degrees. In the first case the voltage is maximum, and in the second, the current is maximum. An intermediate instant would be represented by the curves in Fig. 11. In this case the condensers are still charging, the voltage along the antenna is not yet maximum, and the current has passed its maximum value and is now decreasing. It may be seen that the current is maximum at any point along the antenna at the same instant, although the maximum value of current at any point may not be the same as the maximum at another point. At the time that the current is maximum in the antenna, the current is greatest at the alternator end, and decreases in a sinusoidal manner, being zero at the open or free end. The same thing is true of the voltage. Any point in the antenna reaches its maximum voltage at the same instant, although these maximums will not all be the same. The voltage at the open end of the antenna will be the greatest and will decrease in a sinusoidal manner toward the alternator end. In Figs. 12 and 13 are shown the currents and voltages along the antenna at various instants throughout the cycle. At the time that the current has the distribution shown by curve 1 in Fig. 12, the voltage distribution is represented by curve 1 in Fig. 13.

Instead of showing the currents and voltages present along the antenna at different instants, the usual type of voltage and current distribution diagram indicates only the maximum voltage and the current present at each point as shown in Fig. 14. The curve labeled E is the voltage distribution along the antenna when it is maximum, and the curve I is the current distribution at the time that the current is maximum. It should be realized that these two instants occur at different times.

The curves shown in Fig. 14 are for a grounded quarter-wave antenna, so-called because the dotted lines for the voltage and the current are each one-quarter of a full sine wave, or it is said that one-quarter of a standing wave exists along the antenna. The

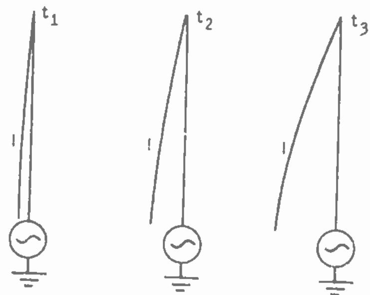


Fig. 12 The current distribution along a quarter-wave antenna at various instances throughout a radio frequency cycle.

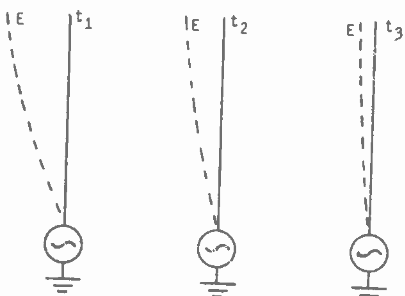


Fig. 13 The voltage distribution along a quarter—wave antenna at various instances throughout a radio frequency cycle.

same type of curves for a half-wave antenna are illustrated in Fig. 15. From these curves, it is seen that the current is maximum at the center of the antenna, and is zero at the two ends, whereas, the voltage is maximum at the two ends, and is zero at the center. The points at which either the current or voltage are maximum are known

Fig. 14 The voltage and current distribution along a quarter-wave antenna.

as loops or antinodes. Thus, points A and C are voltage loops in Fig. 15, while point B is a current loop. The points where the current or voltage are zero are known as "nodes", points A and C being current nodes and point B a voltage node. The same types of distribution curves are shown in Figs. 16 and 17 for a three-quarter wave and a full-wave antenna respectively.

The impedance of the antenna at any point is the ratio of the voltage at that point to the current flowing through that point. Let us consider Fig. 17, which illustrates a full-wave antenna connected to a generator, the other terminal of the generator being grounded. The distribution of voltage and current are shown by the

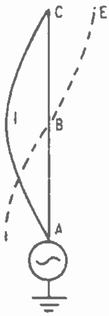


Fig.15 The voltage and current distribution along a half-wave antenna.

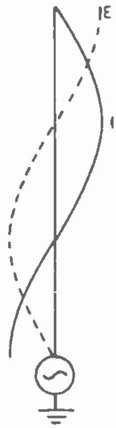


Fig.16 The voltage and current distribution along a three-quarter-wave antenna.

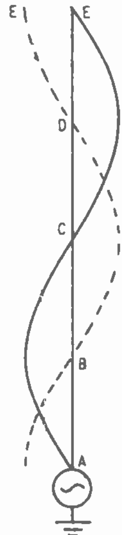


Fig.17 The voltage and current distribution along a full-wave antenna.

sine waves drawn about the antenna itself. It should, of course, be realized that the sine waves represent the maximum current and voltage values, and that the current and voltage are 90 degrees out of phase with respect to time. At points A, C, and E, the voltage is maximum and the current is small. Thus, at these points, the impedance is very high. On the other hand, at points B and D, the current is maximum, whereas the voltage is very low, and these points have low impedance. At intermediate points, the impedance has intermediate values, and may have either an inductive or a capacitive reactance. All points between the open end of the antenna and a point one-quarter wavelength toward the generator have an impedance which is capacitive. Furthermore, all points between one-quarter and one-half wavelength from the open end have impedances which are inductive. Thus, the impedance changes from capacitive to inductive each quarter of a wavelength between the voltage or current nodes.

Full-wave antennas are very uncommon due to the shape of field produced. These will be studied in following paragraphs. Instead, half-wave and quarter-wave types are far more common, one or more half-wave antennas generally being employed in short wave installations, whereas the quarter-wave, half-wave, or five-eighths-wave generally is employed at broadcast frequencies.

The resistance of the antenna, while low, is not negligible, as we shall learn in Section 4, and as a result, the reflected wave has a slightly smaller amplitude than the direct or initial wave. This causes such a condition that the reflected wave is not able to cancel completely the direct wave at the voltage and current nodes, and so the impedance at these points is neither zero nor infinite, but have very low and high values respectively. At these points, however, the impedance has the characteristic of a pure resistance; that is, it contains no reactance. Since the antenna should present a pure resistance to the power source which is feeding it, it may be fed at one or the other of these points.

3. THE HERTZ AND MARCONI TYPES. Fundamentally, there are two general types of antennas; the Marconi and the Hertz. The Marconi type uses the ground as a part of the radiating system; that is, the various distributed capacities of the antenna exist between the antenna and ground. The Hertz antenna is supported well above the ground and neither the antenna nor the feeder system depends upon the ground as part of the current carrying network. The operation of the Hertz is independent of the presence of the ground, except insofar as reflection of the radiated wave by the ground causes interference with the directly radiated wave.

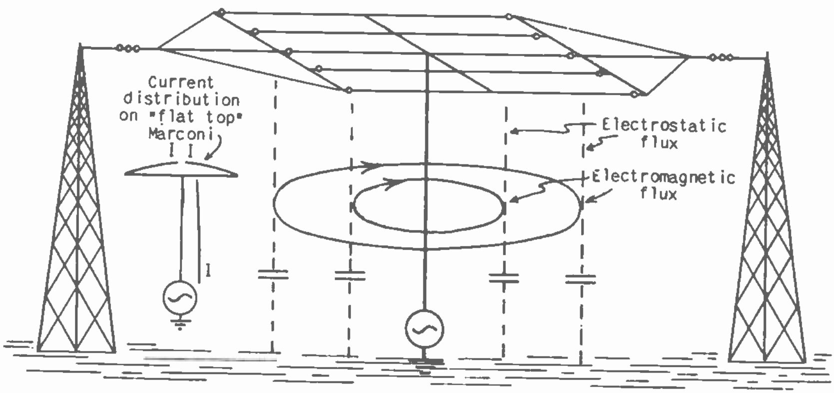


Fig.18 A Marconi antenna of less than one-quarter wave height.

In the old days of broadcasting, the Marconi antenna was used almost exclusively in the form shown in Fig. 18. High towers were quite expensive, so low ones were erected having heights which were only a small fraction of a wavelength. The flat top strung between the towers had a high capacity to ground so that most of the electrostatic flux was exactly vertical. The currents flowing in the down lead had to be fairly high in order to charge this high capacity flat top, and consequently most of the electromagnetic flux encircled the down lead as shown. Since this down lead was a small fraction of a wavelength, the standing wave appearing on it could be neglected. The down lead carried almost uniform current along its entire length. The total flux, or field, produced by such an antenna depended directly upon the current flowing in the antenna and directly upon the height of the antenna.

As towers were made higher and the antenna extended to a quarter-wave as shown in Fig. 14, the current distribution was no longer uniform and the field was not directly proportional to the antenna height. The term *"effective height"* was evolved to represent the height of antenna that would be required, if it were carrying a uniform current, to give the same field as was produced by the quarter-wave antenna having the unequal distribution shown in Fig. 14.

Occasionally the ground was not depended upon to carry the return of the electrostatic flux (resulting in high ground currents) and a *counterpoise* was strung within a few feet of the ground -- similar in appearance to the flat top. Such a system is shown in Fig. 19.

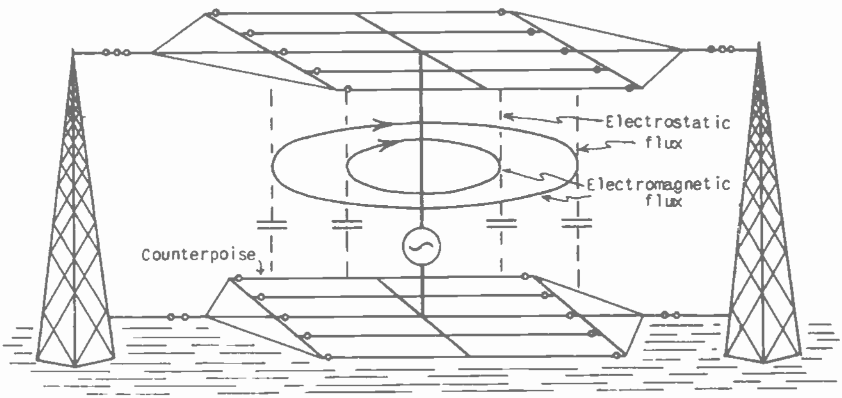


Fig. 19 A Marconi antenna and counterpoise.

The Marconi antenna need not be vertical. It may be erected horizontally (with the exception of the ground connection), or it may consist of both horizontal and vertical portions. However, present practice dictates the use of vertical antennas for broadcast service, and these verticals range in height from slightly over one-eighth to five-eighths-wave, for reasons which we shall consider in this lesson.

If the quarter-wave Marconi of Fig. 14 is used, the current at the base is a maximum and the voltage is a minimum. The impedance is found by dividing the voltage by the current and will be in the neighborhood of thirty to thirty-seven ohms, depending upon the cross section and shape of the radiator and upon the presence of surrounding objects. If the half-wave Marconi of Fig. 15 is used, the current will be a minimum and the voltage a maximum at the grounded end of the tower and the impedance will be in the neighborhood of 400 or 500 ohms for a modern antenna where the vertical tower is itself the radiator. If a single wire down lead is used the impedance may run as high as 2000 ohms to ground.

The lowest frequency at which an antenna may be resonated without the use of additional inductance and capacity is called the fundamental frequency of the antenna. For the Marconi type, this fundamental frequency is that frequency which creates one-quarter of a standing wave along the antenna itself. If this same antenna is operated so that three-quarters of a standing wave is produced, it is called a three-quarter-wave antenna, and this frequency would be the third harmonic of the fundamental. The Marconi will operate at any harmonic of the fundamental.

A Hertz type antenna does not use the ground as a part of the radiating system, and is not connected to ground in any manner. The *presence* of the ground, however, plays an important part in determining the individual characteristics of a particular Hertz antenna. The Hertz antenna is usually a horizontal radiator which may be either center or end fed. The fundamental frequency of such an antenna is that frequency which establishes one-half of a standing wave along the radiator. Thus, it is evident that minimum impedance exists at the center of the antenna, since this point is a current loop and a voltage node in the case of fundamental operation.

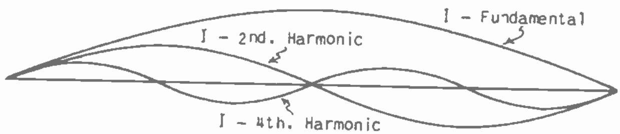


Fig.20 Operation of a Hertz antenna at the fundamental and various harmonic frequencies.

The Hertz may be operated at its fundamental frequency (at which it is a half-wave antenna) or it may be used at any harmonic of the fundamental. Fig. 20 illustrates the current distributions for a Hertz operated at the fundamental, the second harmonic, and the fourth harmonic. Various methods of coupling this type of antenna to a transmitter will be given in a later section of this lesson.

4. ANTENNA EFFICIENCY. The total power dissipated in a dummy antenna is determined by squaring the antenna current and multiplying it by the resistance of the dummy. In an actual antenna used for transmission purposes, however, the current in the antenna depends upon the point considered, it being maximum at a current loop and minimum at a current node. It has become customary to express the total power absorbed by an antenna as the product of the current at a current loop squared, times the total resistance of the antenna. The total resistance of the antenna is, in part at least, somewhat of a hypothetical quantity. The actual ohmic resistance is, and should be, a very small part of this total resistance. This is desirable so that not much power will be lost from the antenna in the form of heat. In addition to this loss, energy is also lost

in the antenna system due to corona effects, eddy currents induced in nearby masts, guy wires, and other conductors; and dielectric losses created by imperfect dielectrics such as trees and other insulators located in the immediate field of the antenna. All of the energy dissipated by these methods may be represented by a loss resistance, which, if placed at a current loop of the antenna, would dissipate the same amount of power as is actually lost through these channels.

The greater part of the antenna power is lost from the antenna due to radiation, and it is through this channel that the major part of the antenna power should flow if the antenna is to be efficient. The magnitude of the power lost by radiation is customarily represented by a fictitious "radiation resistance" which is a resistance of such a value that it would dissipate the same amount of power as is actually radiated, if it were placed at a current loop in the antenna. The value of this radiation resistance is dependent on the antenna construction, the mode of operation; (that is, whether it is operated as a quarter-wave, half-wave, etc.) and the relation of the antenna to ground and other nearby conducting objects. As an example, the radiation resistance of a Marconi quarter-wave antenna is approximately 36.2 ohms, whereas a half-wave Hertz that is remote from the ground has a radiation resistance of about 72.4 ohms.

The total resistance of the antenna is the loss resistance which includes the ohmic resistance of the antenna, and the radiation resistance. The efficiency of the antenna is:

$$\text{Efficiency} = \frac{R_r}{R_r + R_l}$$

Where: R_r is the radiation resistance, and
R_l is the loss resistance.

This formula represents the fraction of the total energy supplied to the antenna, which is converted into radio waves. With a given frequency, and other factors remaining constant, the radiation efficiency varies with the ratio of the antenna height (h) to the wavelength (λ). This is due to the fact that the radiation resistance (measured at the current loop) is roughly proportional to the antenna height, whereas the antenna losses increase slowly if at all with increased height. On the other hand, if this ratio of h/λ is kept constant as the wavelength is reduced, the radiation efficiency of the antenna will increase. This results from the fact that the radiation resistance remains constant as this ratio remains unchanged, but as the high frequency antenna is smaller, its loss is correspondingly less, and a larger proportion of the energy which is furnished to it is converted into useful radiation. Thus, the radiation efficiency of short wave antennas is high, often as great as 90%, whereas long wave antennas used for very low frequencies may have radiation efficiencies as low as 5%.

5. ANTENNA TUNING. It has been shown that the resonant points of an antenna are at the quarter-wave, half-wave, and three-quarter-

wave points, etc. At these points the impedance presented by the antenna is a pure resistance and is equal to the loss resistance plus the radiation resistance, it being understood that the same resistance will not be obtained at all of these points. At intermediate points, the impedance of the antenna will contain some reactance, and the only way that the antenna could be fed efficiently at these points is to introduce into the antenna circuit sufficient reactance of opposite sign to cancel the reactance of the antenna.

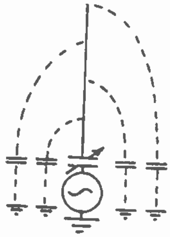


Fig.21 Series capacity applied to an antenna that is too long.

When a Marconi antenna is electrically an exact multiple of an odd quarter-wavelength; (that is, one-quarter, three-quarters, etc.) it does not need to be tuned, and the impedance it presents to the transmitter is a pure resistance. However, it is not practical to attempt to construct an antenna of exactly the right length to produce resonance, since the proper length will be influenced by external factors such as soil conductivity, nearness of trees and other objects. For this reason, a quarter-wave antenna might

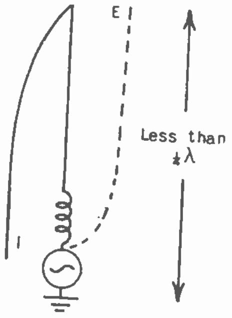


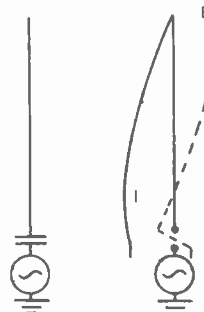
Fig.22 Series inductance applied to an antenna that is too short.

be constructed slightly shorter than normal, and then its effective length could be increased by adding inductance in series with the antenna. When the antenna is less than one-quarter wave, it has a net capacitive reactance, which may be cancelled by adding series inductance. Such an antenna is said to be loaded. For reasons of economy, an antenna might be made one-eighth wave long and then loaded up to a quarter-wave. An antenna of this type would still be called a one-eighth wave antenna.

On the other hand, if an antenna is somewhat longer than normal, it will have a net inductive reactance which may be neutralized by connecting a condenser in series with the antenna. This is illustrated in Fig. 21, and it is seen that the condenser which is added, is in series with the capacity existing between the antenna and ground, and therefore, the total capacity of the antenna is reduced. It is necessary to have some sort of coupling arrangement between the transmitter and the antenna, and often this is an antenna pick-up coil, whose inductance will add to the total inductance of the antenna circuit. Thus, a series-connected condenser will ordinarily be needed to cancel the inductance of the pick-up coil.

Fig. 22 shows the effect on the voltage and current distributions of adding an inductance in series with the antenna. It is seen that the current is uniform through the coil but that the voltage changes. This figure is for an antenna which is somewhat shorter than one-quarter wavelength. The impedance at the base of the antenna is a pure resistance since the excess capacitive reactance has been cancelled, however, the amount of the resistance is somewhat less than in a quarter-wave antenna, since the voltage at the base is not as large. An antenna with a series shortening condenser is illustrated in Fig. 23. Again the current through the condenser is constant, whereas the voltage suffers a phase reversal.

Fig.23 The current and voltage distribution along a series capacity tuned antenna.



6. **THE GROUND WAVE AND THE SKY WAVE.** The energy which is radiated from a transmitting antenna, located at the earth's surface is conveniently divided into a ground wave which travels along the surface of the earth, and a sky wave which is projected upward into the atmosphere above the earth. The strength of the ground wave at the antenna is determined by the field radiated along the horizontal, but as this ground wave travels away from the transmitting antenna, it becomes weaker as a result of spreading and because of energy absorbed from the wave by the earth. The ground wave induces charges in the ground and since these charges travel along with the wave, they represent a current which dissipates energy. Thus, the portion of the wave in contact with the earth will be continuously and rapidly wiped out, only to be replenished, at least in part, by the diffraction of energy downward from the portion of energy immediately above the earth. This causes the

strength of the ground wave to be attenuated with distance in a complicated manner.

That part of the R.F. energy which is directed upward into the atmosphere above the earth likewise suffers some attenuation. This is especially true in daylight, since certain radiations from the sun cause a small amount of ionization of the air particles, thus making the air slightly conductive. The attenuation produced by the air, however, is exceedingly small, compared to that suffered by the ground wave which lies close to the earth.

Naturally, the wave which is directed toward the upper atmosphere will not be effective for reception purposes unless it is reflected back to earth. The fact that it is reflected, accounts for long distance radio communication. The ground wave is attenuated rapidly, and at distances of 50 or so miles from the antenna, it is so weak as to be no longer useful. The wave which is directed into the upper atmosphere is called the "sky wave" and is reflected downsard from a layer of ionized air which is known as the "ionosphere", or the Kennelly-Heaviside layer, after the men who propounded it.

The existence of this ionized air was suspected shortly after Marconi was successful in transmitting signals across the Atlantic in 1901. It was realized that some explanation was necessary, since these waves, similar to light, were unable to follow the curvature of the earth. Heaviside in England and Kennelly in the United States

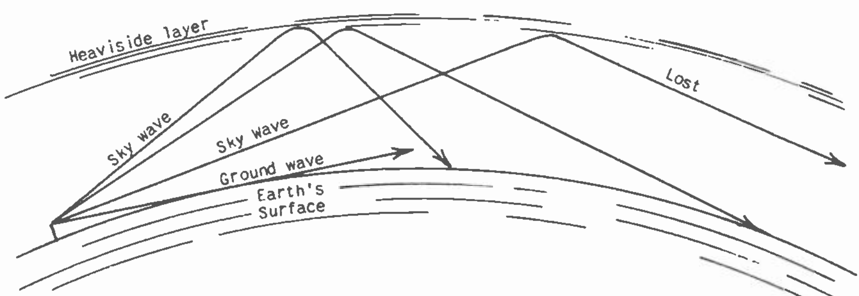


Fig.24 Sky wave transmission by reflection from the Kennelly - Heaviside layer.

suggested that the waves were reflected from an ionized layer in the upper atmosphere and were thus confined to the earth. Investigation in recent years has led to considerable modification in the original theories. Experiments have shown that there is *not one, but several ionized layers* and, instead of the wave being reflected from the conducting layer, as light is from the surface of a mirror, it enters the medium and is sent back to Earth again by refraction. This process is illustrated in Fig. 24. Notice that the radio wave, instead of experiencing a sharp reflection, is bent slowly as it enters the ionized region, and is finally directed again toward Earth. For purposes of explanation, however, it is convenient to consider the process as one of simple reflection whereby the wave travels with the velocity of light to a hypothetical reflection plane from where it is reflected at the same velocity.

The height of this plane is called the virtual height of the layer, as is indicated in Fig. 25.

The amount of bending which a wave suffers depends upon the degree of ionization as well as upon the frequency of the wave itself. With the density of ionization constant, the amount of bending will diminish with an increase of frequency and, at some *critical value of frequency*, the wave will penetrate the lowest ionized layer and be reflected from some more strongly ionized layer above the first. As the frequency is further increased, a point will finally be reached where the wave is not bent sufficiently, even by the most highly ionized layer, to cause it to return to Earth. Thus, wavelengths below *approximately* 8 meters (37 megacycles) are not ordinarily useful for long distance communication since the bending they experience in the ionosphere does not cause them to be directed toward the earth.

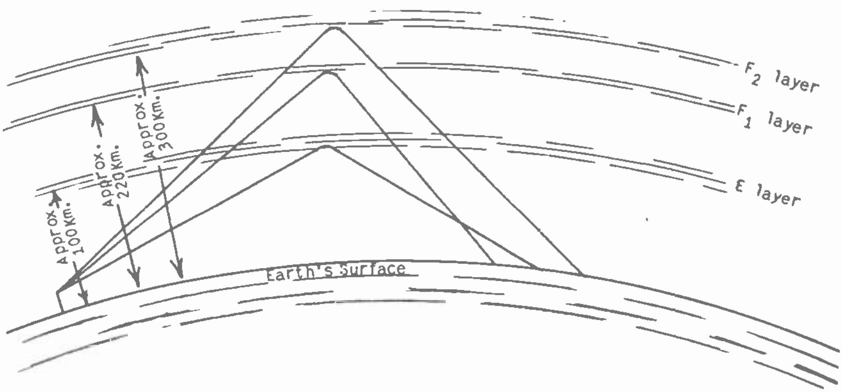


Fig.25 Virtual heights of ionized layers.

The lower part of the ionosphere is known as the E region, and above this there is a more intensely ionized F region which is 100 to 200 miles above the surface of the earth. The F region is composed ordinarily of two distinct layers known as F_1 and F_2, the virtual height of which may change abruptly. On some occasions, these two layers merge into a single layer and, at times, two distinct layers are also observed in the E region.

The critical frequency above which the wave is not reflected from a particular layer depends not only upon the degree of ionization of the layer, but also upon the angle of incidence which the ray or beam forms with the reflecting layer. Naturally, a beam which is nearly perpendicular to the plane of the layer will not be bent sufficiently to cause it to return to earth, no matter what the frequency of the beam may be. If the ray strikes the layer at some odd angle, such as 45 degrees, it may or may not be returned to earth, depending upon its frequency. If the angle which the beam makes with the layer is very small; that is, an angle which a beam leaving the antenna in a nearly horizontal manner would make, then all except the ultra-high frequencies will be returned. Thus, it is seen that for any given frequency, there is a critical angle which will cause the beam to be returned to earth, and for all greater angles, the beam will merely be bent and will pass through the ionized layers. This information is given in graphical form in Fig. 26. The horizontal scale of this graph shows the maximum vertical angle in degrees which will cause reflection from the ionized layer.

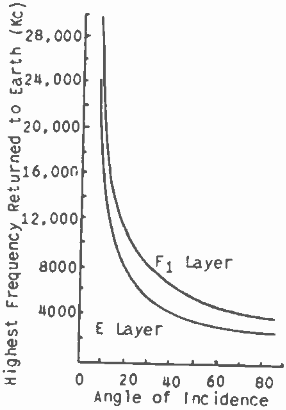


Fig.26 Critical angles for reflection from the ionosphere.

The vertical scale of this graph illustrates how this critical angle varies with frequency. Frequencies which lie above this curve will not be bent sufficiently to return to earth and, hence, will not be used for transmission purposes beyond the range covered by the ground wave. Of course, the position of these curves vary with the degree of ionization which changes throughout the day, being normally much higher at noon than at midnight. The ionization also changes with the seasons of the year, in cycles of eleven years each, and in a miscellaneous manner throughout the year, depending upon sun spots, magnetic storms, and for some unknown reasons. It is thought that the ionizing agent responsible for these layers is probably ultra violet light from the sun, and when a given part of the atmosphere is in the earth's shadow, the height of the layer is correspondingly increased.

7. PROPAGATION OF LOW FREQUENCY RADIO WAVES. Low frequency radio waves ranging from approximately 20 kc. to 550 kc. suffer very little ground wave attenuation. In fact, the amount that the ground wave is attenuated varies directly with the frequency. For distances up to about 600 miles, nearly all reception of signals in this band is through the medium of the ground wave. Within this range, the strength of the received signals is practically independent of the ordinary daily, seasonal, and yearly variations which affect other bands. The sky wave is considerably less than the critical frequency even for rays directed upward at an angle nearly 90 degrees with respect to the ionosphere. Thus, the only attenuation which the sky wave suffers is that caused by spreading plus the additional loss which occurs at the earth's surface and the edge of the ionosphere.

Transmission of low frequency radio waves throughout distances greater than that which the ground wave may serve, suffer daily, seasonal, and yearly changes which affect the layers of the ionosphere. When the path between the transmitter and the receiver is in daylight, the attenuation is greatest, since the under layer of the ionosphere approaches the earth, and for the wave to travel a given distance, many more reflections are required, each of which add to the total loss. The principal drawback of long wave transmission is the necessity of employing antennas of very large dimensions which are cumbersome and very expensive, and, of course, the lack of the available channels at these frequencies.

8. **PROPAGATION OF BROADCAST FREQUENCIES.** Throughout the broadcast band, the attenuation of the ground wave is large; much larger than for low radio frequencies. Attenuation of the sky wave is very great during the day time, and day time communication is due entirely to the ground wave. The night time attenuation of the sky wave is variable, and is determined by the height of the ionosphere. At times, the attenuation becomes moderately high, and at other times there is practically no night time attenuation. This results in the daytime coverage being comparatively small, although the signals can always be depended upon, barring the disturbing influence of static. Even at night, the ground wave accounts for most

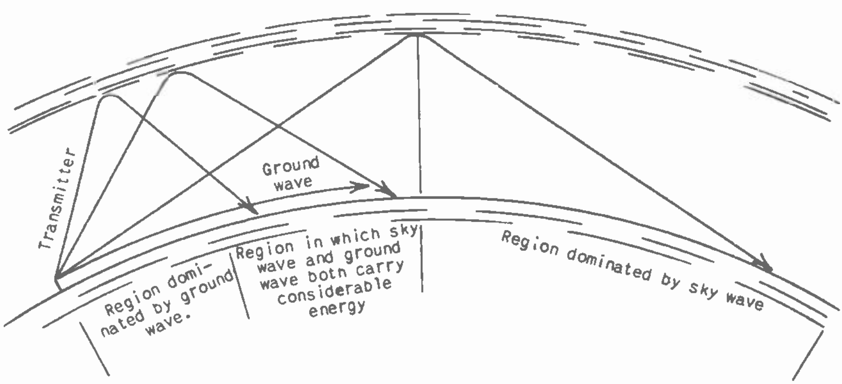


Fig.27 Night coverage of a high powered broadcast station.

of the energy received at local points, although appreciable energy from the sky wave may reach very distant points far beyond the daytime coverage. Fig. 27 illustrates the conditions existing at night. It is seen that there are three distinct zones. At points near the transmitter, the ground wave is considerably stronger than the sky wave, and it contributes most of the signal energy to local receivers. Somewhat farther away from the transmitter, the strength of the ground wave has decreased, and that of the sky wave has become greater until they are of approximately the same magnitude. If it so happens that the energy received from each is in phase, the resultant signal will be strong, but if they are of opposite phase, a partial or total cancellation will result and reception will be impossible.

Whether the two waves are in phase or not, depends upon the distance traveled by the sky wave in comparison to the ground wave. This distance is determined by the virtual height of the ionosphere, and since this height is variable and changes at short periodic intervals, reinforcement of the two waves will follow a cancellation, and periodic fading will result.

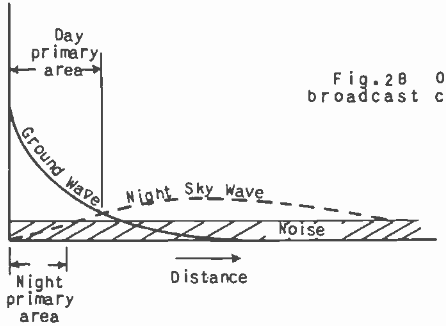


Fig.28 Optimum conditions of broadcast coverage.

At distances still further from the transmitter, at points where the ground wave has become so attenuated that it is no longer of service, the sky wave will be strong enough to make reception very good, although consistent reception cannot be expected, since the variable height of the ionosphere will change the amount of energy which the sky wave delivers to any one locality. Curiously enough, however, the signal intensity produced by the sky wave does not diminish appreciably throughout the range served by the sky wave. As may be seen from Fig. 27, the energy which reaches a point remote from the transmitter, is produced by a sky wave radiated at low angles, and since most broadcast antennas are designed so that the lower the angle above the horizontal, the greater is the radiated energy, points at great distances from the antenna receive almost as much signal as those closer in, despite the increased attenuation of the wave which travels the longer distance. Distant night time reception, which depends on the sky wave, is slightly superior on the high frequency end of the broadcast band due to the longer angle of reflection from the ionosphere. On the other hand, the attenuation of the ground wave varies directly with the frequency, and daytime reception dependent on the ground wave is better from the lower frequency stations. The received field varies directly as the square root of the power.

Fig. 28 shows the different types of coverage obtainable from a broadcast station. The lower part of the graph is shaded and indicates the noise level, it being understood that the signal strength must be above the noise level to be heard. The day primary service area extends to the point at which the strength of the ground wave is enough greater than the noise to give understandable and nearly noise-free reception. It is to be noticed that the night time primary area is of smaller magnitude than the corresponding day coverage. At night the sky wave causes some interference with the ground wave and there is a range throughout which considerable distortion and fading are present.

Beyond the primary service area is the secondary service in which reception is not quite as consistent, although the ground wave is still strong enough to give some service, provided that the noise level is not too high. It has been determined that for consistent satisfactory reception, the signal strength should be between 5 and 30 (millivolts per meter) for metropolitan areas, but need be only 0.1 (millivolt per meter) for rural districts where the noise level is low.

In the area where the ground and sky waves have approximately the same strength, distortion of the signal often results. It has been stated that the two waves may either add or subtract, depending on their relative phase at the point of reception. It has furthermore been determined that this interference between the two waves is dependent on frequency, and a slight change in frequency will affect the relative path lengths by an appreciable fraction of a wavelength. Now since a modulated radio frequency wave consists of a carrier and a number of sideband frequencies, it often happens that part of the frequencies in the sideband of the sky wave are in phase with the corresponding frequencies of the ground wave, whereas others may be of opposite phase, producing a cancellation which naturally distorts the quality of the received signal. This phenomenon is known as selective fading, and it has been discovered that two frequencies differing by as little as 250 cycles may fade in and out independently of each other.

8. **PROPAGATION OF SHORT RADIO WAVES.** The ground wave of frequencies above 1600 kc. is attenuated so rapidly that it is of no importance except for communication over relatively short distances such as would be required by a municipal police station. Thus, short wave communication depends primarily upon the refraction of the sky wave to the receiving point without excessive attenuation. This causes the signal strength at a distant point to depend upon the transmitted frequency, the conditions of the ionosphere, the angle at which the wave enters the ionized region, and the power at the transmitter. Fig. 29 shows the paths followed by short waves of different frequencies. At A, it is assumed that the transmitted frequency is less than the critical frequency even for rays which strike the ionized layer at a large vertical angle. In this case, nearly all of the rays are returned to earth. At B in this same figure are shown the ray paths of a somewhat higher frequency; one of which is higher than the critical frequency. The rays which strike the ionosphere with nearly vertical angles are refracted only slightly and do not return to earth. Thus, the first sky wave which returns to earth, does so at a considerable distance from the transmitter. It is seen that there is a region where no energy is re-

ceived from the transmitter between the point at which the ground wave has suffered so much attenuation that it is no longer useful, and the point at which the sky wave first returns to earth. This is called the skip distance and throughout this region, reception from the transmitter is impossible. Increasing the frequency further increases the extent of this skip distance, since only rays

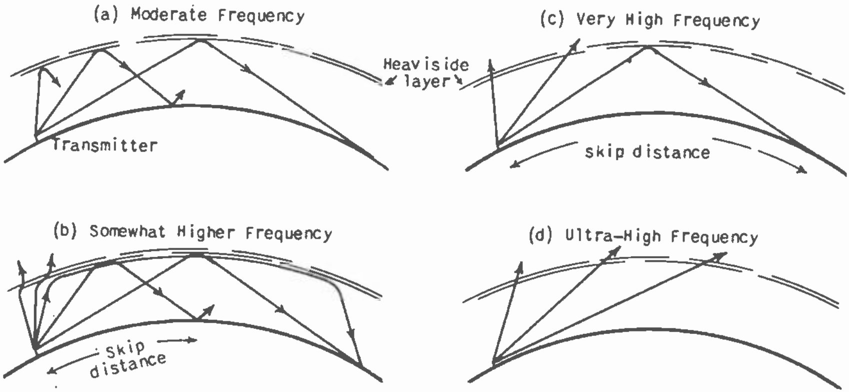


Fig.29 A comparison of sky waves at various frequencies.

which leave the transmitter at nearly a horizontal angle will be returned. This condition is illustrated at C in this figure. Ultra high frequencies are not returned at all, since even those rays which leave the transmitter in a horizontal direction are not sufficiently refracted by the ionosphere to cause them to be returned to earth. This condition is shown at D in Fig. 29.

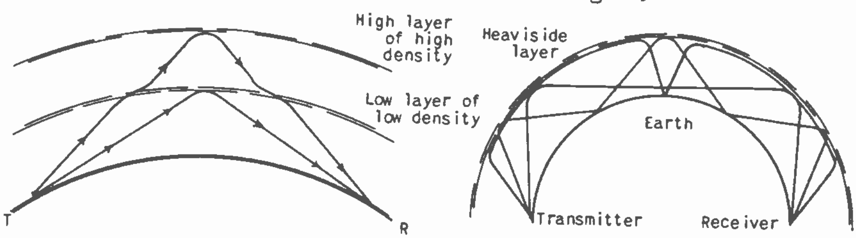


Fig.30 Multiple path transmission of the sky wave signal.

It should be realized that in reality, the ionosphere may consist of several layers, and those rays which do not suffer sufficient refraction to be returned by the first layer may be caused to do so by the effect of a higher layer where the ionization is more intense. Thus, two waves leaving the transmitter at widely different angles might return to earth at the same point as illustrated in Fig. 30A. The low angle ray which is near the horizon is refracted from the lower layer of the ionosphere, whereas the ray which is nearly vertical, suffers multiple refraction and is finally returned to the same point as the first ray.

There are, in fact, numerous paths which a signal may take in traveling from a transmitter to a receiver. Consider Fig. 30B. From this figure, it is seen that many paths are possible for the wave to take in traveling from the transmitter to the receiver; four such paths are shown in this figure. The attenuation along these different routes will differ considerably; those rays which cross the edge of the ionized layer the fewest number of times will be attenuated the least.

It has been found that the amount of attenuation which a sky wave suffers, varies inversely as the square of the frequency, and so a high frequency wave will be attenuated less than one of low frequency. It would thus appear that short waves would be more desirable for long distance communication than long waves. Such is actually the case, although for any given distance of transmission there is an optimum frequency. If too high a frequency is employed, there is the possibility that the receiver will lie within the skip distance and will therefore receive no energy. Thus, the optimum frequency is the highest frequency which may be used without skipping over the receiver.

The greater the distance between the transmitter and the receiver, the higher is the optimum frequency which may be used. Likewise, a higher frequency is permissible in daylight than at night, and a somewhat higher frequency may be used in summer than in winter. If the transmission is over a comparatively short distance, the frequency used should not exceed the critical frequency for rays which strike the ionosphere nearly vertically. In fact, it should not exceed this critical frequency appreciably even for transmission distances up to 500 miles. Since the ionosphere is nearer the earth in the daytime, a higher frequency may be employed without causing the receiver to be in the skipped zone; that is, the sky wave will be returned to earth at a point nearer to the transmitter and will not pass over the receiver. For reliable communication between relatively near points, two frequencies should be employed, one for day use and one for the night. A frequency in the neighborhood of 300 kc. will give very good results at night, whereas one of approximately 6000 kc. would be suitable for daylight communication. Of course, the lower frequency could also be used during the day, but would give somewhat more attenuation than the higher frequency.

For long distance communication, the optimum frequency in the daytime is about 20 mc. and 10 mc. at night, but will vary during different seasons of the year. It is for this reason that communication between fixed points is usually carried on with several different frequencies. One frequency will be necessary for daylight use, another for night, and perhaps a third for the transition period between day and night, or for unusual conditions which sometimes exist.

There is a decided difference between the transmission of short wave radio signals in a north-south direction and those in an east-west direction. When the transmission path is in a north-south direction across the equator, both receiver and transmitter as well as the path between them, have about the same amount of sunlight, although the seasons are reversed. Conversely when the transmission path is in an east-west direction, both points have the same season, but one may be in darkness and the other in full sunlight.

10. DIRECTIONAL CHARACTERISTICS OF ANTENNA. Up to this point we have considered the process of generating the radiation field of

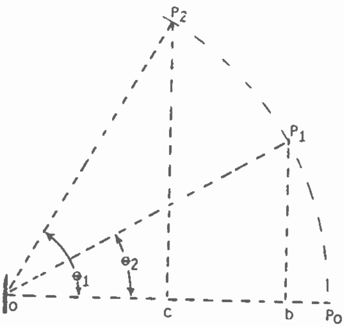


Fig.31 The effect of direction of transmission upon the field of a simple antenna.

the antenna, and we have studied the propagation and utilization of the radiation from the antenna. In this section we shall consider the ability of the antenna to radiate energy in various directions;

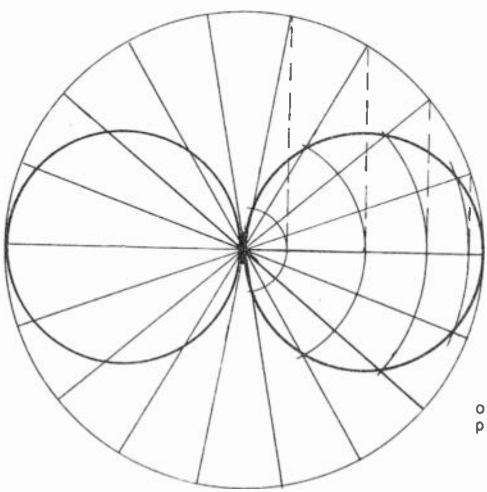


Fig.32 The directivity of a short antenna in the plane of the wire.

that is, north, south, east, or west, and at various angles upward with respect to the Earth's surface.

If it were possible to produce a constant current in a very short length of wire in free space, such as the wire (1) of Fig. 31, then the radiation from that wire would be maximum at right angles to the wire and zero off the ends of the wire. At other angles with respect to the axis of the wire, the field delivered by this elemental antenna would assume intermediate values between zero and maximum. For instance, in Fig. 31, if we take the field in the direction OP_o as unity, then the field strength at P_1 would be given by O_b and the field strength at P_2 would be given by O_c. We can arrive at the field strength in any direction above the horizontal line O_p by plotting a circle about the antenna and dropping perpendiculars from the circle to the line P_o'. If the student is familiar with trigonometry, he will recognize this construction as specifying the condition that the field at any point about the antenna is proportional to the cosine of the angle to that point with respect to the perpendicular through the antenna wire. Following this construction through in Fig. 32, we see that the field about an elemental antenna is a figure 8, and that each half of the figure is a perfect circle. To interpret a radiation pattern such as Fig. 32 or Fig. 33, the student can visualize the radiation pattern as a graph of the *magnitude of the field strength measured at equal distances* from the antenna (for example: 1 mile) in all directions; or as a plot of the distance one would have to go in every direction from the transmitter to obtain equal field strengths, assuming perfect transmission.

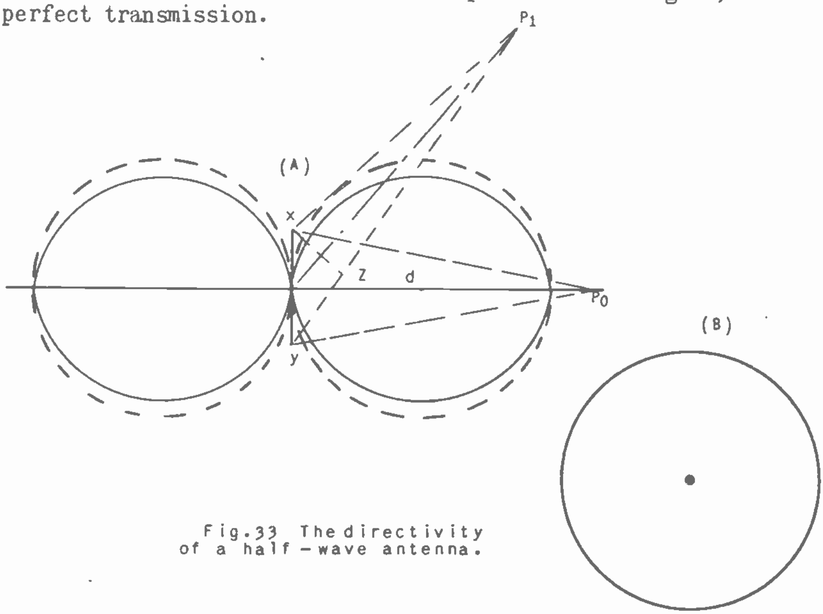


Fig.33 The directivity of a half-wave antenna.

The structure is just slightly more complicated in the case of a half-wave antenna or any other *practical length*, but the principle is evident in Fig. 33. Regardless of the current distribution on the antenna XY, provided current flows in the same direction (which it does in the case of a half-wave antenna), the field from all points along the antenna XY will add at the point P_0. This is true, because if the point P_0 is far enough away from the antenna, all points on the antenna are equidistant from P_0.

However, at some other angle away from the antenna, the field from all points of the wire do not add. Consider the point P_1. One end of the antenna, such as X, will be closer to the distant point than will be the opposite end of the antenna Y. The differential length between these two points and the distant point P_1 is given by the distance YZ. Thus, it can be seen that the field from the point Y will arrive at the distant point some time later than the field which emanates from the point X. Since the field from point Y arrives later than the field from point X, the two fields cannot be in phase upon their arrival and the result is that the field from points X and Y do not add up directly. In fact, if the point P should be taken nearly off the end of the antenna, then the field from Y would almost cancel the field from point X. Thus, the relative field about a half-wave antenna is not quite the same as the field which existed about the elemental antenna. The field pattern about a half-wave antenna is still a figure eight, but the lobes are not quite circular. The comparison between the elemental antenna and the half-wave antenna is shown by the dotted line and the solid line respectively in Fig. 33. Looking at the end of the antenna in Fig. 33B, we see that the field radiates uniformly in all directions away from the antenna.

To understand the performance of an antenna in any particular direction, it is necessary to consider Fig. 33A and Fig. 33B at the same time. In other words, the radiation about the half-wave wire is in the form of a doughnut as illustrated in Fig. 34.

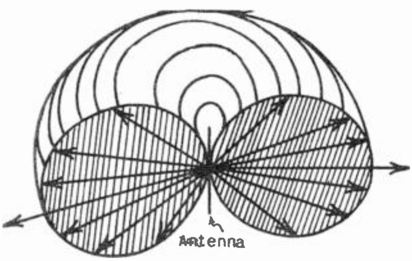


Fig.34 Section of "doughnut" radiation pattern obtained from a free space vertical radiator.

In practice, antennas are never operated in free space, so that the foregoing comments must be modified to include the effect of the ground, or of other antennas or objects nearby. Nearby objects or antennas absorb part of the field of the antenna and re-radiate it. This re-radiated field adds to, or subtracts from, the field of the main antenna, depending upon the relative phase of the two fields. Thus an insulated wire in the vicinity of the antenna might either increase or decrease the field in that direction and thus distort the pattern of the main antenna. This will be better understood after we have covered the next section on antenna arrays.

The presence of the ground below an antenna affects the shape of the radiated pattern with respect to the angle of transmission above the Earth's surface. The reason for this is that the ground reflects the field radiated from the antenna and the reflected field then adds to, or subtracts from, the antenna field, depending upon the relative phase of the two. This is illustrated in Fig. 35.

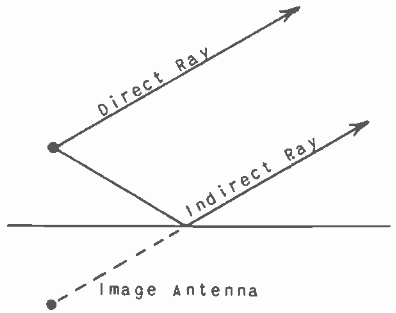


Fig.35 The effect of the ground upon the field from a horizontal antenna.

It can be seen in this figure that the reflected ray or indirect ray travels a longer path to a distant point than does the direct ray from the antenna. Furthermore, the reflected ray suffers a phase reversal upon reflection. The ground behaves as a mirror and creates, in effect, an image antenna below the surface of the Earth.

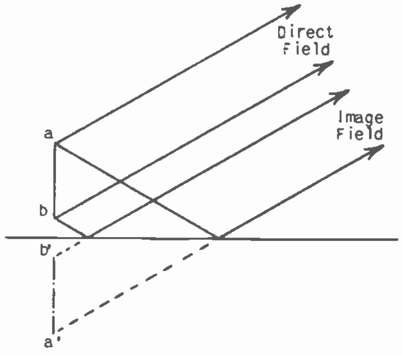


Fig.36 The effect of the ground upon the field from a vertical antenna.

If the antenna is *horizontal*, then the image antenna is just as far below the surface of the earth as the actual antenna is above it, and furthermore, the *image antenna carries a current 180 degrees out of phase to the actual antenna.* In Fig. 36, the same case is shown for the vertical antenna. Here it is noted that in addition to the phase reversal that accompanies the reflection from the surface of the earth, the image is effectively turned upside down. Thus the *vertical* antenna behaves as if a similar antenna was placed an equal distance below the surface of the Earth and carrying a current *in phase* with the main antenna.

The effect of the ground upon the vertical antenna is to lower the angle of radiation as can be understood from considering Fig. 37, which shows a half-wave antenna above ground, and its image. Since the currents of the two antennas are in phase, the fields add up at point P_1. At some other point *above* the Earth's surface, such as P_2, it takes longer for the field from the image antenna to reach the point than it does for the field of the main antenna.

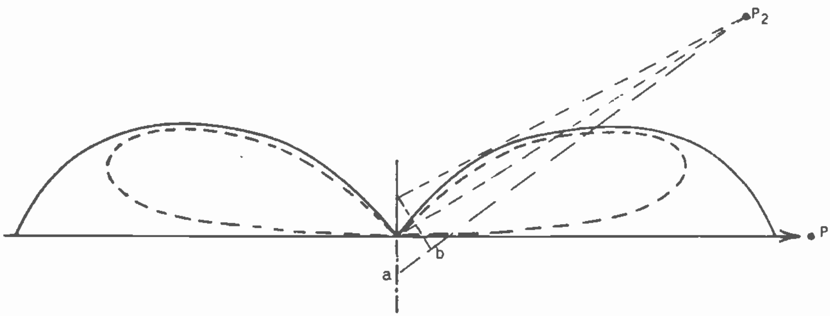


Fig.37 The vertical radiation pattern of a half-wave vertical antenna close to the ground.

The distance a-b, therefore, constitutes a delay of the image field and lowers the magnitude of the radiation at point P_2 in comparison to that of point P_1, since the two fields fail to reinforce completely at point P_2. If this procedure was accurately followed for all points equidistant from the antenna, we would arrive at the solid curve shown in Fig. 37, illustrating the vertical directivity of the antenna. The predominance of low angle radiations explains why the vertical half-wave antenna has gained so much acceptance for broadcast use. The low angle radiation is further increased by extending the length of the antenna to five-eighths of a wavelength, as shown in Fig. 38. Notice that the ground wave has been increased

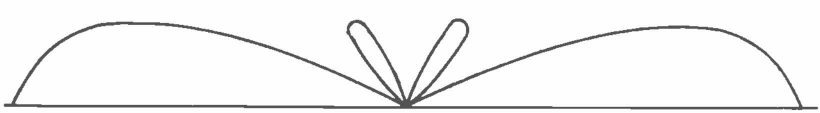


Fig.38 The vertical radiation pattern of a five-eighths wave vertical antenna close to the ground.

over that of Fig. 37, but that an additional high angle radiation lobe has come into play. For broadcast use, it is sometimes more important to suppress this high angle radiation than it is to obtain a great deal of ground wave because this high angle lobe of radiation may reflect from the ionosphere and cancel or add to the ground wave at some distance from the transmitter, producing an undesirable amount of fading.

In the practical case, the ground is not a perfect conductor so that the reflected wave is weaker than the main wave (or direct field) due to the losses encountered in the ground upon reflection. More important than this fact is the phase shift that results in a reflected field when the ground is not a perfect conductor. The phase shift of the reflected field causes it not to add with the

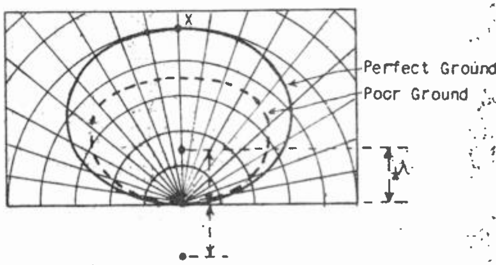


Fig.39 The vertical radiation pattern of a horizontal dipole, located one quarter-wave above ground.

direct field of the antenna in the horizontal direction. This lowers the field strength of the ground wave tremendously as shown by the dotted curve of Fig. 37.

Returning now to the horizontal antenna, Fig. 39 was plotted by the method outlined for Fig. 37 considering that the current flowing in the image antenna was of opposite phase to the current flowing in the main antenna. In the horizontal direction along

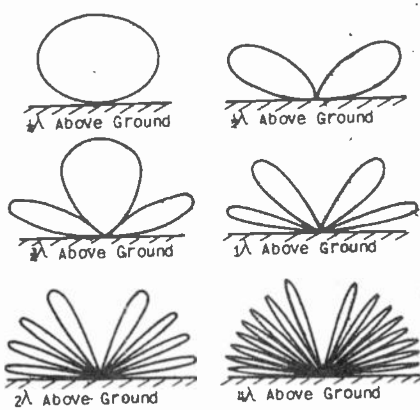


Fig.40 The vertical radiation patterns of horizontal dipoles, located at various heights.

the surface of the Earth, any point would be equidistant from the two antennas; that is, the main antenna and the image antenna. Since the currents flowing in these two antennas are out of phase, the field would be zero, thus no radiation takes place along the Earth's surface. Directly above the antenna (point X of Fig. 39) the field from the two antennas will add because they are 180 degrees out of phase and they are a half-wave apart. The field from the image antenna in traveling to point X, takes 180 degrees longer than the field from the main antenna and since it starts out of phase, it therefore arrives at point X in phase with the field of the main antenna. Intermediate points between the vertical and the horizontal position assume intermediate values of fields.

The effect of a poor ground is not so serious in the case of a horizontal antenna as it is in the case of a vertical antenna since it reduces chiefly the vertical radiation which is of little use. The dotted line of Fig. 39 shows this effect.

If the antenna is raised a considerable height above ground, say, for instance, four wavelengths above ground, then the difference in path lengths for the fields from the image antenna and the main antenna is zero in the horizontal direction and eight wavelengths in the vertical direction. At points in between, the difference in path length is, of course, between 0 and 8 wavelengths. Consequently, as we consider the various angles above the surface of the earth, the field from the image antenna alternately reinforces and cancels the field from the main antenna. This effect is shown in Fig. 40 for various heights of transmitting antennas. The effect of imperfect ground is to fill the nulls of radiation and to slightly lower the angle of maximum radiation.

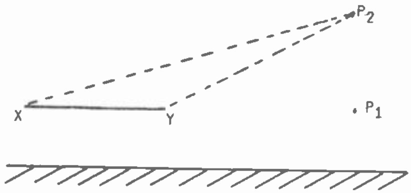


Fig.41 The effect of the vertical angle of radiation upon the horizontal directivity of an antenna.

In considering the effect of the ground, we have indicated only the directivity of the antenna in the vertical plane. Of course, we are interested in whether the antenna covers all directions effectively; that is, whether it covers north and south as well as east and west. All of the vertical antennas which have been drawn will produce a circular pattern about the antenna; that is, they radiate equal energy in all directions. This is true for any particular vertical angle of radiation. Let us emphasize again that it is necessary to think in terms of both the horizontal and the vertical directivity at the same time. Thus, while a vertical antenna produces equal energy in all directions, neglecting the disturbing effects of surrounding objects, at the same time, it will give more field immediately along the Earth's surface than is propagated upward toward the ionosphere.

In considering the directivity of the horizontal antenna in Fig. 33, the pattern was plotted in the plane of the antenna wire; that is, antenna XY is assumed to lie directly upon the sheet of paper. This is not a practical case. We are not normally concerned with the radiation from a horizontal antenna directly along the

Earth's surface since this type of antenna is used chiefly for short wave installations where the sky wave is important. Redrawing the horizontal antenna as in Fig. 41, it may be seen that the radiation in line with the antenna along the surface of the Earth is

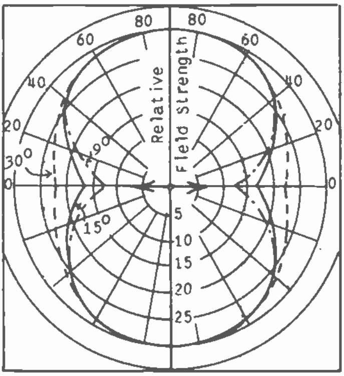


Fig.42 The horizontal directivity of a vertical half-wave antenna shown for three vertical angles of radiation.

zero at point P_1, since this point lies directly off the end of the antenna, XY. At some elevation above the Earth's surface, however, considerable radiation does take place. This is obvious if we consider the antenna in free space illustrated in Fig. 33 as turned upon its side in Fig. 41. Thus the horizontal distribution of the field at *useful vertical angles* is not as shown in Fig. 33, but as in Fig. 42. This figure shows the horizontal directivity of the antenna at three different angles above the surface of the Earth.

11. ANTENNA ARRAYS. Antenna arrays may be divided into two general classes, depending upon the purpose of their installation. First, are the complex arrays of various sorts designed for point

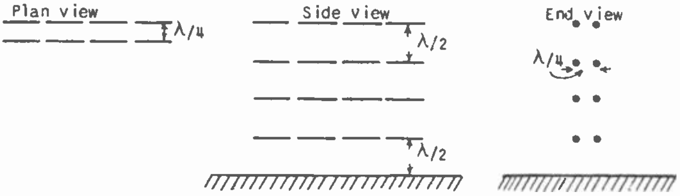


Fig.43 Broadside antenna array composed of 32 half-wave radiators.

to point communication, the purpose of which is to concentrate all of the radiated energy of the transmitter in the direction of the receiving station and to do this at the optimum vertical angle. The antenna arrays which we shall consider in the second classification are less complex and are those systems incorporated by broadcast stations for the purpose of protecting certain areas served by other transmitters operating upon the same or adjacent channels.

The arrays used for point to point communication may be subdivided as follows. First are the "curtains" of numerous half-wave antennas, properly spaced and fed with proper phase relation in order to take advantage of the interference between the fields produced by the individual elements. The second type of array consists

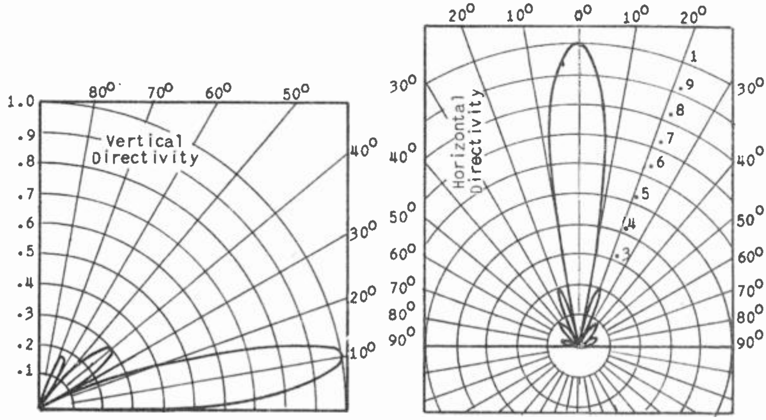


Fig.44 Horizontal and vertical directivity of the array illustrated in Fig. 43.

of a number of antennas which are fed with power from a transmitter and an equal or greater number of antennas which are located close to the driven elements, but which are not connected to the transmitter in any way. Either of these two classes of antennas may be

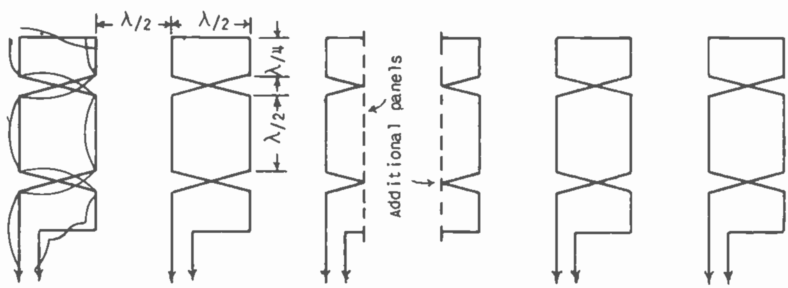


Fig.45 Compact antenna array.

arranged in such a way that the portions of the radiators producing the least field are folded up, thereby making a more compact array but one of lower efficiency than the fundamental array from which it was derived.

An antenna array composed of 32 half-wave antennas is shown in Fig. 43. The directivity of this antenna is shown in Fig. 44.

Sixteen of the elements are fed *in phase* from the transmitter, while the other sixteen elements are located to the rear of the driven elements and act as parasitic reflectors; that is, they are resonant, and excited by induction from the driven antennas, rather

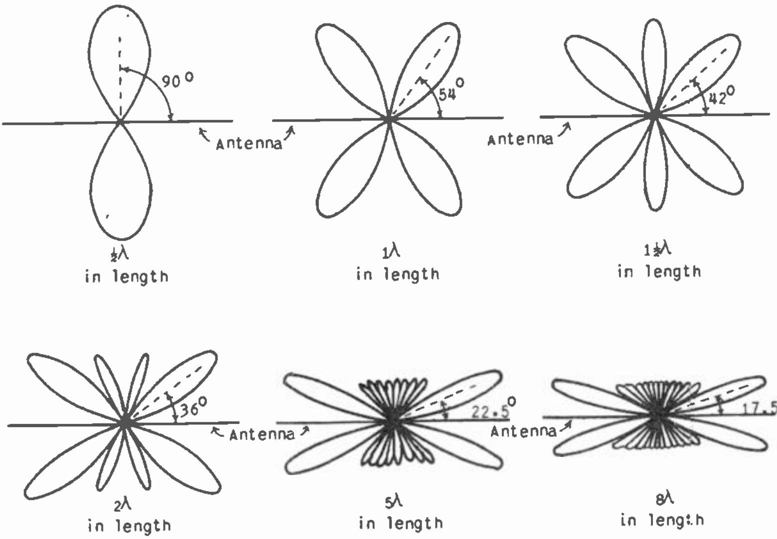


Fig.46 Radiation patterns existing about single wires of various lengths.

than being coupled directly to the transmitter. One type of array which is folded up to reduce its physical size is shown in Fig. 45. This general scheme was used in one of the trans-Atlantic telephone systems, although it is not as common as the antenna array shown in Fig. 43.

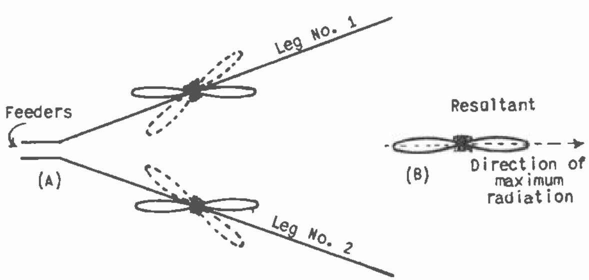


Fig.47 The V-beam antenna.

In addition to the arrays consisting of numerous half-wave antenna elements, excellent directive antennas may be formed by taking advantage of the directive properties of long wires. If a long wire is excited at a frequency such that several standing waves exist along the wire, radiations from part of the wire cancel radiations from other parts of the wire in certain directions and add up in other directions. The fields existing about several lengths

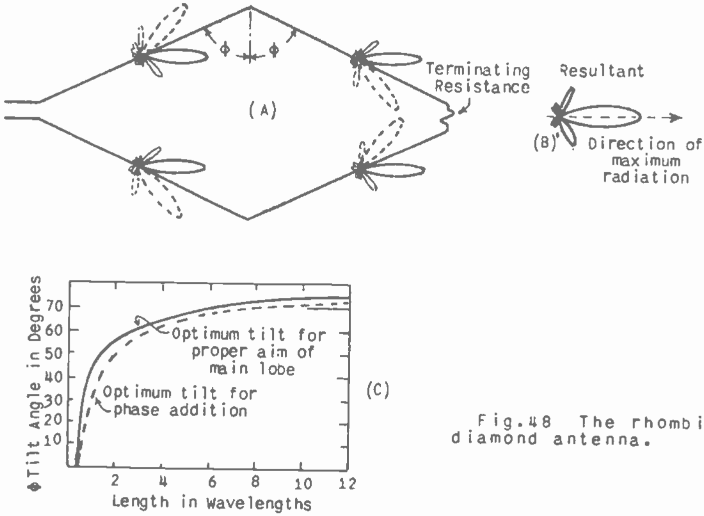


Fig.48 The rhombic or diamond antenna.

of wire are shown in Fig. 46. Two or more long wires may be combined in various manners such that some of the radiation lobes of the long wire are cancelled while others are reinforced. The two most common types of antennas employing this principle are the V antenna of Fig. 47 and the rhombic antenna of Fig. 48. The dotted

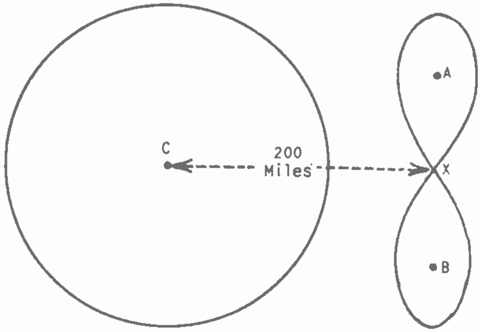


Fig.49 The use of an antenna array in affording interference protection for the service area of another transmitter.

portion of these figures represents the radiations from the individual wires which are cancelled by out-of-phase radiations from some other wire in the system. Since this lesson is concerned chiefly with broadcast antennas, the subject of short wave directive arrays has been limited and the student should realize that numerous other types of arrays are quite practical.

The directional antenna as employed by broadcast stations has two major functions. The first and probably the least important is to concentrate the radiated energy in the direction of the largest service area. For instance, a station located at the seashore might erect an array designed to eliminate the radiations toward the ocean and concentrate this energy toward the inland areas where the greatest population lies.

The other function of the directive antenna system for broadcast use is the protection of stations on the same channel or adjacent channels. Suppose, for instance, that a transmitter site is chosen which lies between two large cities such as A and B of Fig. 49. Assume further that the channel assigned to station X lying between these two cities differs by only 10 kc. from the channel assigned to the station located at C which is 200 miles distant from X. If a single antenna were used at station X, the power would have to be limited to such an extent that it would not interfere with the service area of station C. Under these conditions it might not be possible to obtain satisfactory noise-free signals in cities A and B. However, by the use of two towers placed along the line between A and B and fed 180 degrees out of phase, a figure eight pattern would result which would effectively cover the two nearby metropolitan areas without interference with the service of station C.

A more complicated case is illustrated in Fig. 50. Here it is desired to protect three stations by erecting a three-element array. This protection was obtained with an increase in field toward the main service area at the same time. The elements of this array are located on three corners of a square and fed with equal currents, although the current in one of the antennas leads the current in the other two by 90 degrees as indicated in the figure.

The two arrays just described produce symmetrical coverages, but this is not necessarily the case. By placing three or four antennas at various positions and feeding them at various phase relations and with various current ratios, it is possible to obtain almost any desired pattern. The flexibility that can be achieved is apparent from a study of Figs. 51 and 52. These figures show the types of pattern that can be obtained with equal currents flowing in only two radiators for the case of Fig. 51, while Fig. 52 shows the case of only one antenna and one reflector. More complicated patterns can be obtained by the use of a larger number of elements. Fig. 51 is plotted for eight different spacings between the two antennas and for five different phase relations between the equal currents which flow in the two elements. Fig. 52 shows the effect of varying the spacing between the driven antenna and the parasitic reflector and also the effect of varying the tuning of the parasitic reflector. Circles are plotted on the same figure to show a comparison with a simple vertical antenna.

It has previously been indicated that the distribution about a pair of antennas can be plotted by taking into account the phase relation between the fields which are produced by the two antennas. This phase relation may be divided into two parts: first, the phase difference between the currents which are flowing in the two wires, resulting in one field being *produced sooner or later* than the field from the other antenna; second, the phase shift due to the *difference in time of propagation* of the field from one antenna with respect to the other in reaching a certain point remote from the antenna.

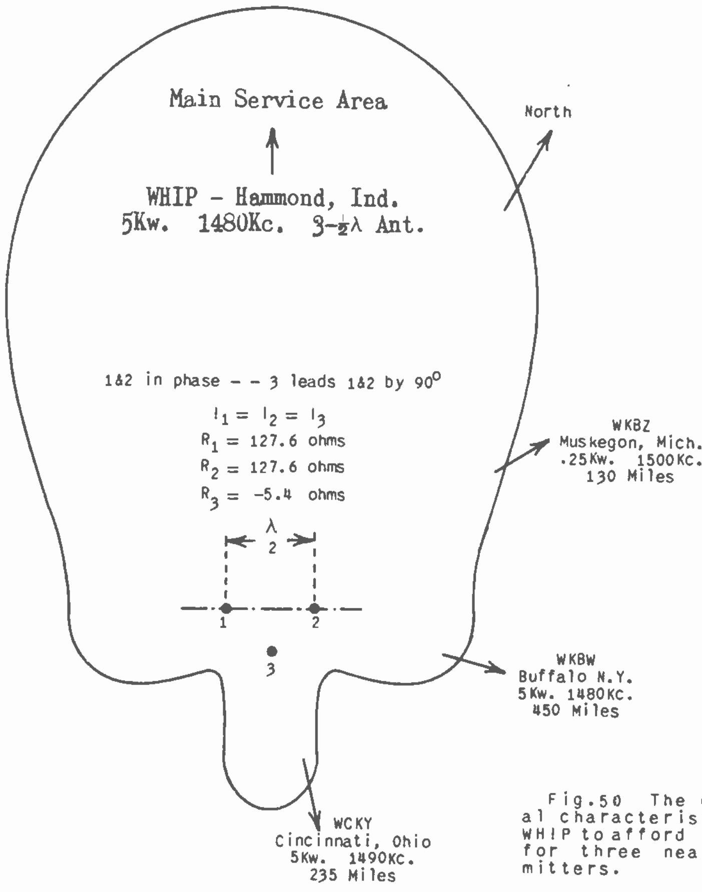


Fig.50 The directional characteristic used by WHIP to afford protection for three nearby transmitters.

When one antenna is not driven, but is excited by the field of the other antenna, we say that this element is parasitic. It is excited due to the mutual induction existing between the two wires, just as the current flowing in the secondary of a transformer is produced by the current flowing in the primary of the transformer. The current which flows in the parasitic reflector is not the same as the current that flows in the driven antenna and depends upon the mutual impedance existing between the two antennas and upon the

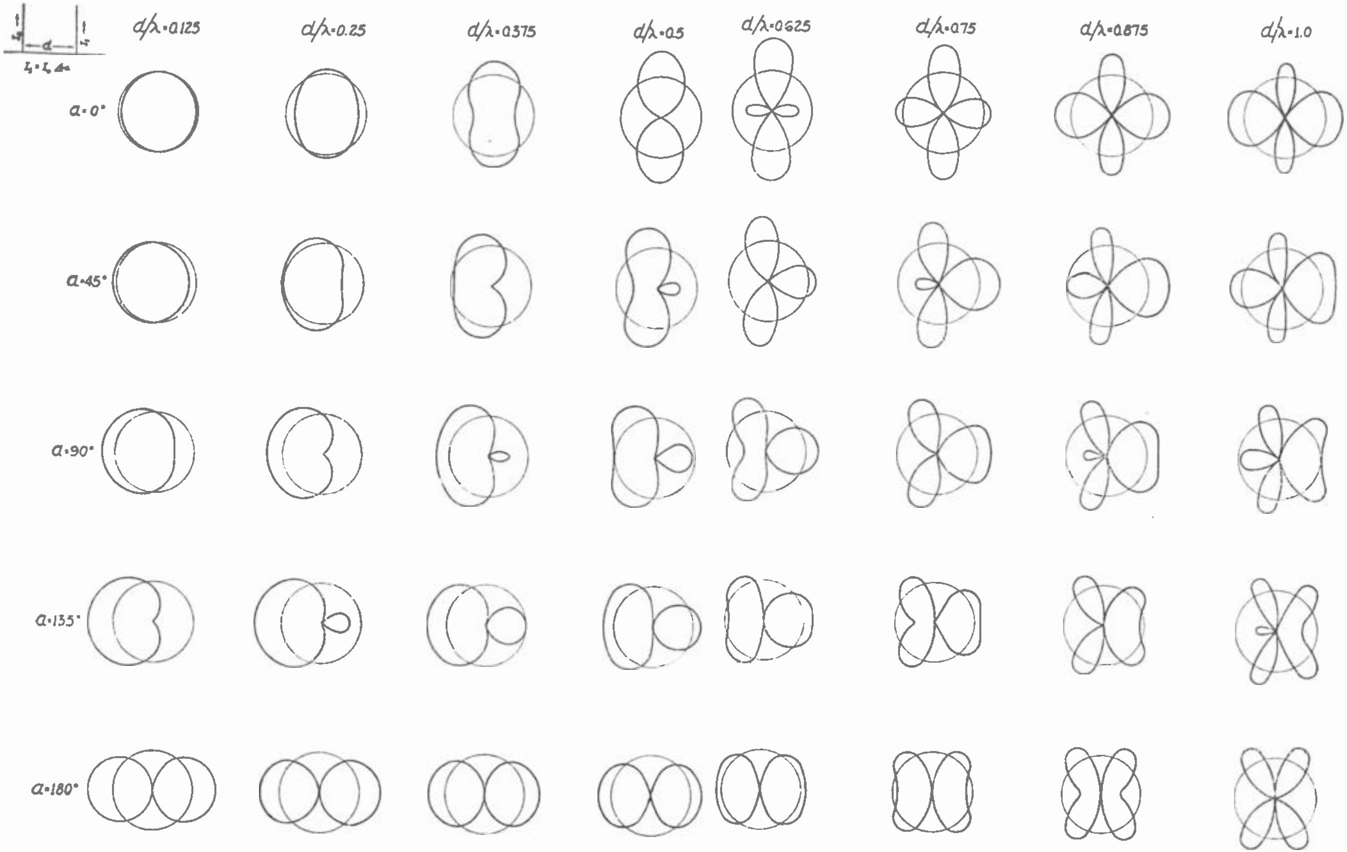


Fig.51 Variations in the directional pattern obtainable from two similar driven antennas.

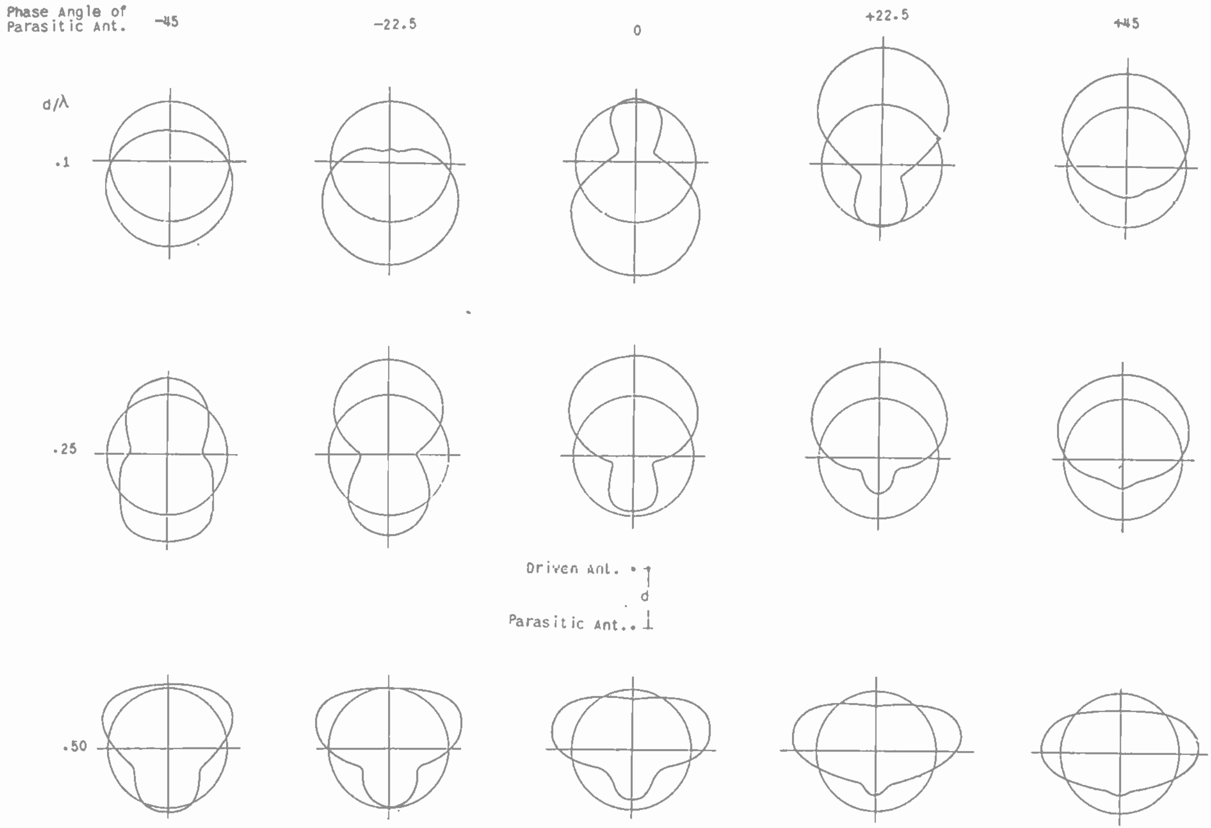


Fig.52 Variations obtainable in the directional characteristics of one driven and one parasitic antenna.

radiation resistance of the parasitic reflector. Since the current in the parasitic antenna is not the same as that in the driven antenna, neither will the fields from the two antennas be the same. Therefore, in plotting the curves of Fig. 52, it was necessary to take into account not only the phase relation in the fields from these antennas, but also the actual ratio of their magnitude.

Since it takes a certain length of time for the field to get from the driven antenna to the parasitic antenna, the voltage induced in the parasitic antenna necessarily lags the current flowing in the driven antenna. However, the current flowing in the parasitic antenna may either lead or lag the voltage induced in this antenna, depending upon the amount and sign of the reactance in the parasitic element. Thus, if we make the parasitic element shorter than necessary to produce resonance. the capacitive reactance produced will cause the current to lead the voltage. Conversely, if the parasitic element is made longer than necessary to produce resonance, it will be inductive and therefore the current will lag the voltage. Thus we are able to control the shape of the pattern as shown in Fig. 52 by altering the length of the parasitic element. By simply shifting the length of the element a few per cent, it becomes either a director or a reflector; that is, it causes maximum radiation to occur either toward the parasitic element or away from it.

Another interesting effect of locating two antennas close together is the change in input impedance that occurs. This is true, regardless of whether the two antennas are driven or whether one of them is a parasitic element. If the two antennas are located an eighth-wave apart, the radiation resistance is no longer 72 ohms at the middle of the antenna, but may be as low as 10 ohms. Furthermore, the length which was required to tune the antenna to resonance no longer produces resonance when the second antenna is brought close to the first, due to the *mutual reactance* existing between the two antennas. Thus in tuning up an array, any change made in one antenna necessitates a change in the other and aligning an antenna array of several elements becomes a very tedious task unless the performance of the entire system is thoroughly understood. The process will be covered in a general way in a later lesson.

12. THE FACTORS AFFECTING BROADCAST COVERAGE. Among the factors which determine the coverage of a broadcast station are the transmitter, the directive characteristics of the antenna, the transmitter frequency, the soil characteristics, and the noise level. Just how these different factors affect the covering power of a station is shown graphically in Fig. 53. At A in this figure is shown the effect of transmitter power. With low power as shown by the dotted lines, both the ground wave and the sky wave are relatively weak. The primary service area is small and the sky wave is everywhere too weak to provide a secondary service area. Thus, whatever secondary service area that is present is the result of the weakened ground wave and is approximately the same for night and day.

With a larger transmitter power, as represented by the solid lines, the ground wave is now sufficiently strong to provide adequate coverage out to the point where the sky wave and the ground wave are of approximately the same strength, and distortion and fading occur. The overall result is that the daytime coverage area produced by the ground wave is considerably greater than at night, since at night the region of fading produced by the sky wave falls within the daytime service area. On the other hand, beyond the area of fading, the night sky wave is strong enough to provide relatively good coverage.

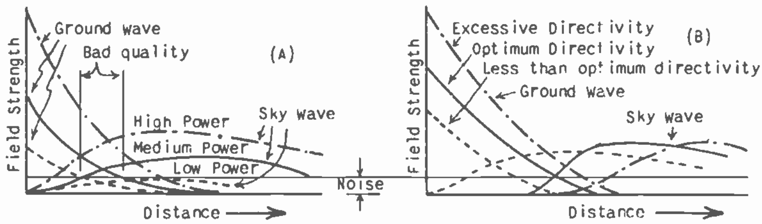
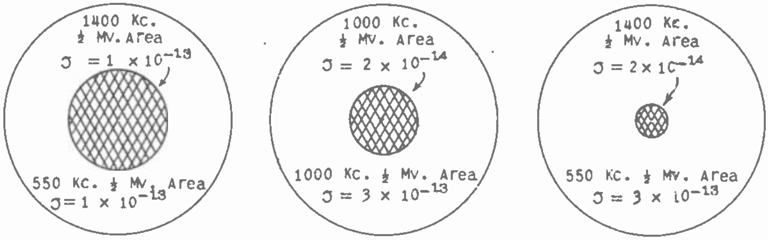


Fig.53 Factors affecting broadcast coverage.

A still further increase in the transmitter power produces the results shown by the dashed lines. The ground wave is increased which naturally causes the daytime primary and secondary service areas to extend over a greater range. The night-time primary coverage, however, is no better than with a lower amount of power, because the outer portion of the day primary area is within the region of bad fading produced at night. It should be understood that increasing the transmitter power beyond a certain point does not materially increase the range of the night-time primary coverage area because of the interference of the ground and sky waves. At distances far from the transmitter, the sky wave is quite useful, but it is a decided disadvantage for points near to the transmitter since it produces fading and distortion by interference with the ground wave. Thus, the only way of taking advantage of an increased transmitter power is to eliminate the sky wave at points near to the transmitter. It is those rays which strike the ionosphere at nearly a vertical angle which cause the interference, and so the proper procedure for remedying this situation is to design the antenna so that most of the energy is radiated at a low horizontal angle. This action will increase the intensity of the ground wave and at the same time reduce the near sky wave, thereby causing the fading region to be pushed farther away from the transmitter.

The effect of this sort of antenna directivity is illustrated at B in Fig. 53. It should be noticed from this figure that there is an optimum amount of antenna directivity. Excessive directivity reduces the high-angle sky wave to such an extent that the ground wave dies out before the sky wave returns to earth and creates a region where the signals are received weakly, if at all, during both



1700 Mv/M at one Mile.
σ = Coefficient of Soil Conductivity.

Fig.54 The effects of frequency and soil conductivity upon the primary service areas of broadcast stations.

day and night. The ideal amount of directivity is obtained when the sky wave is negligibly small until the ground wave becomes too weak to be satisfactory, and then comes in abruptly with an intensity somewhat greater than the ground wave. With this ideal condition, the night coverage of the ground wave is the same as the day coverage and the region of high distortion and fading is reduced to a minimum.

The amount which the ground wave is attenuated depends to a large extent upon the soil conductivity surrounding the antenna.

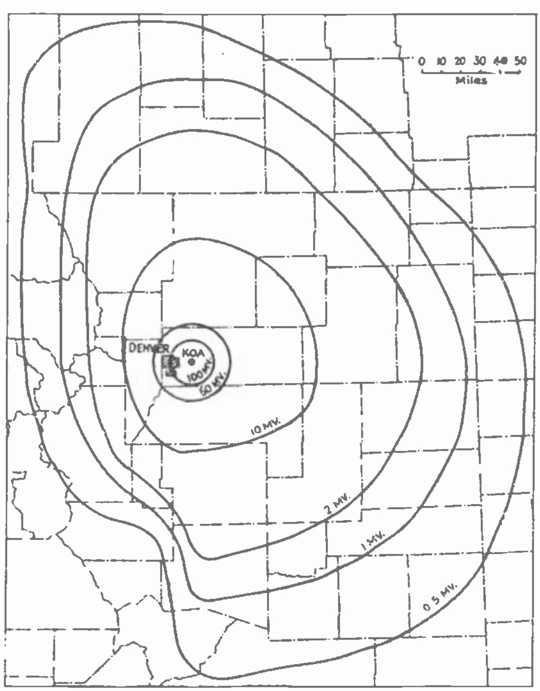


Fig.55 Measured field strength of radio station.

Good conductivity creates a minimum amount of attenuation and increases the ground wave without affecting the sky wave appreciably. Thus, the amount of optimum antenna directivity depends on the soil conductivity, the transmitter power, and the frequency, since all of these factors affect the strength of the ground wave.

The effects of frequency and soil conductivity are shown in Fig. 54. The left hand figure shows the relative areas that can be covered with the same station operating on opposite ends of the broadcast band. The center figure shows the effect of varying soil conductivity upon the areas that a particular station can cover when operating on a particular frequency. The right hand drawing of Fig. 54 shows the combined effect of the other two figures and illustrates the tremendous differences in performance that can be anticipated from stations operating with the same amount of power.

Fig. 55 illustrates the effect of varying soil conductivity, hills, intervening objects, etc. upon the field distribution about a vertical antenna; which would, except for these factors, produce a uniform pattern in all directions (concentric circles of field strength contours).

13. THE VERTICAL RADIATOR. Practically all of the recent installations of broadcast antennas have been of the self-radiating steel tower type, with a height of between one-eighth wave, and five-eighths wave. An antenna of this type may be excited by insulating the base from the ground by large compression insulators, and then applying the excitation voltage between the base and ground.

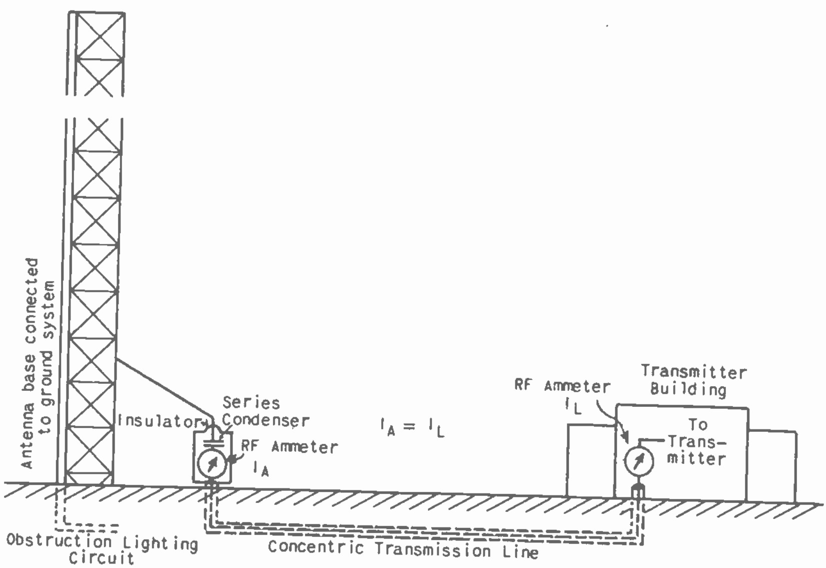


Fig.56 The shunt-excited antenna.

This is called a series-fed antenna and is the usual method of procedure, although some of the later types have the antenna tower grounded at its base. In this case, the excitation voltage is applied by means of a wire attached to the tower at a height above ground of about 20% of the height of the tower. This type is known as a shunt-excited antenna, a schematic diagram of which appears in Fig. 56. The inductance of the lower part of the antenna is resonated by means of the condenser C contained in the feed wire. Thus, this loop is tuned to the resonant frequency of the antenna, and the voltages developed across the lower part of the tower excites the entire antenna. The advantage of this system is that the base insulators which are quite expensive need not be used. The current distribution on a shunt-excited antenna is shown in Fig. 57.

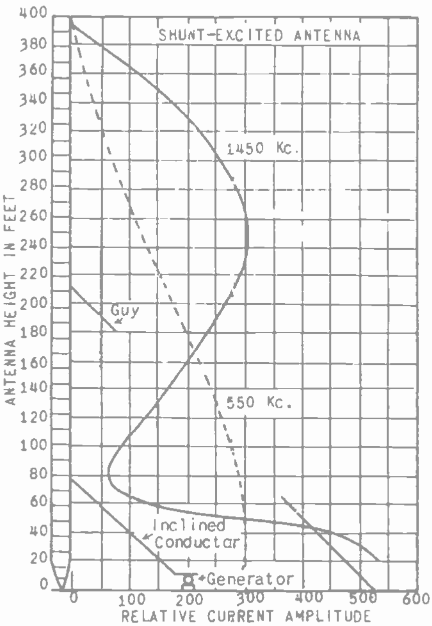


Fig.57 Current distribution on a shunt-excited vertical tower.

It is desirable that vertical radiators be as narrow as possible, and that they have a uniform cross section, consistent with structural stability. A vertical radiator may be either guyed or self-supporting. The self-supporting type is the more economical except for towers of great height. In fact, the only advantage of the guyed type is that the cross section can be made more nearly uniform than the self-supporting type, which must, necessarily, have a base wide enough to insure sufficient rigidity. The purpose of making the cross section uniform is to simulate as closely as possible the ideal thin wire so that the current distribution will approach sine wave form. This is particularly true of antennas designed for optimum heights near five-eighths wave. A slight decrease in height diminishes the magnitude of the ground wave, while a slight increase in height increases the sky wave to such an extent that severe fading results at the edge of the prime service area. The non-uniform current distribution on tapered towers effects the vertical directivity in a manner which is hard to allow for in the design of the tower height.

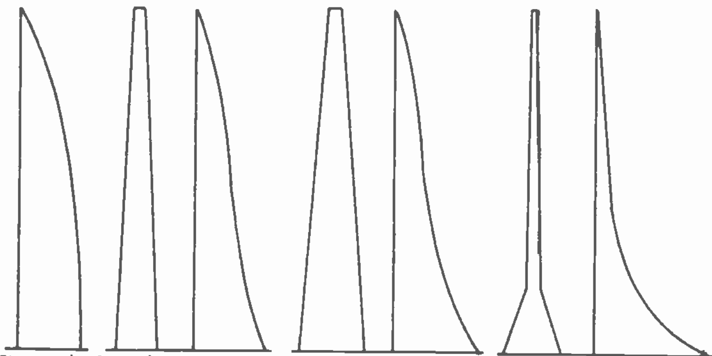


Fig.58 Current distributions on towers of various shapes.

In Fig. 58 are shown in outline form several towers of different tapers and also the current distribution of each. At A is the theoretical vertical wire whose current distribution is of sine wave form. B illustrates a tower with a uniform taper and a narrow base. The effect of the taper is to make the current increase near the base of the tower. C shows a tower with a uniform taper and a wide base; in this case, the increase of current at the base is even more apparent. Finally, D illustrates a tower with a flared base, for which construction, the current increases very abruptly at the base of the tower. It may be proved that a structure which tapers uniformly from top to bottom is better than one which flares out abruptly near the base or is subject to sharp changes in outline. With the flared type, the upper parts of the antenna have very little capacity with respect to ground compared to the lower parts, and very little current flows to them. Fig. 59 illustrates two types of modern vertical radiators; the self-supporting tapered tower and the guyed uniform cross section tower.

The tower must be mechanically strong enough to withstand the loads placed upon it by wind pressure, dead weight of the structure, and, in some cases, the added weight of ice and sleet. The principal loading effect is that due to wind pressure. Unlike a roof truss or a floor beam, where the loadings are within reasonable range of control, a tower is of such a height that the wind pressures are exceedingly variable. The tower is subjected to wind from all directions, and the velocities may have different maximums at various elevations above the ground. Thus, much of the design of the tower must be left to the judgment of the engineer.

It is important in the design of a radiator that attention be

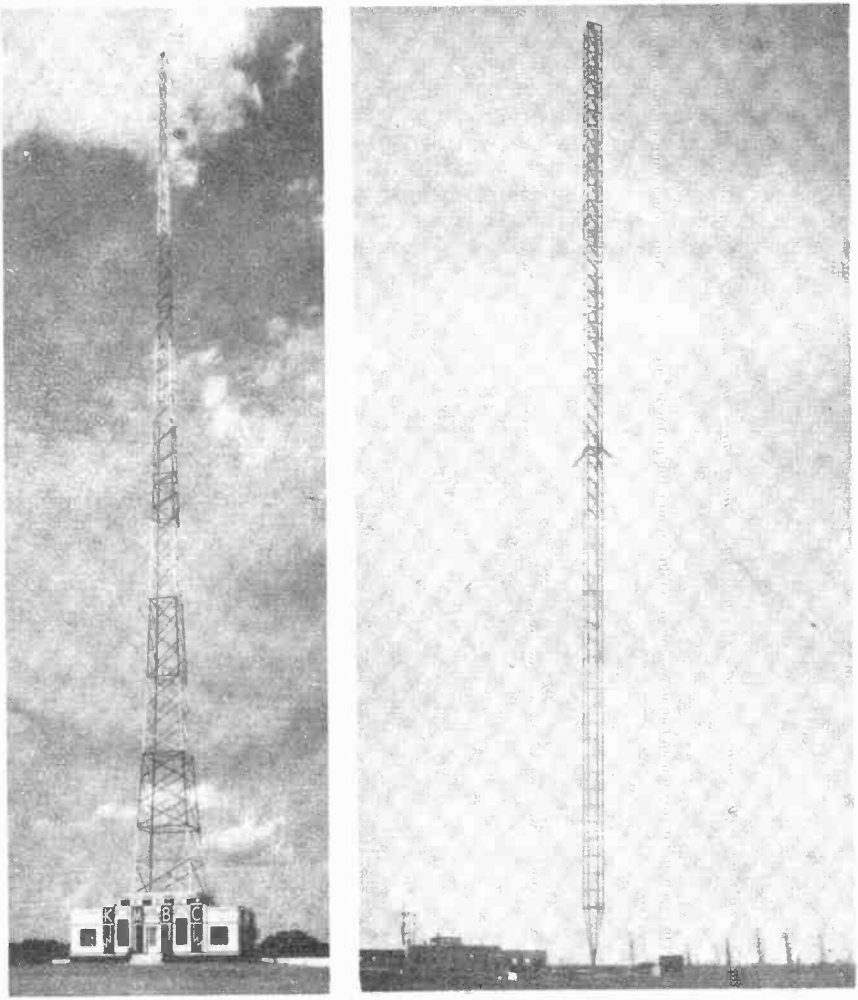


Fig.59 Self-supported versus guyed towers.

given to the type of insulators used. It has been found that porcelain has the best dielectric qualities of any material able to withstand the heavy mechanical loads. This material has a high compressive strength, but is very unreliable when placed under tension, therefore, care must be taken that the load is one of pure compression.

The electrical requirements of the insulator which must be considered are the wet and dry flashover voltages, continuous operating voltage, and the proper leakage distance along the porcelain.

If the latter two requirements are met, it is found that the flash-over voltages are within the allowable limits. It is very important that the insulators be capable of withstanding the operating voltage continuously at radio frequencies without overheating. Typical 50 kw. stations operate with a voltage of between 4,000 and 8,000 RMS across base insulators having capacities of 30 mmfd. A conservative limit for the temperature rise is considered to be 50° F. There must be a sufficient length of porcelain between the metal parts of the tower and ground so that there will not be an appreciable current leakage during wet or misty weather. Experience has indicated that this distance should not be less than 6 inches.

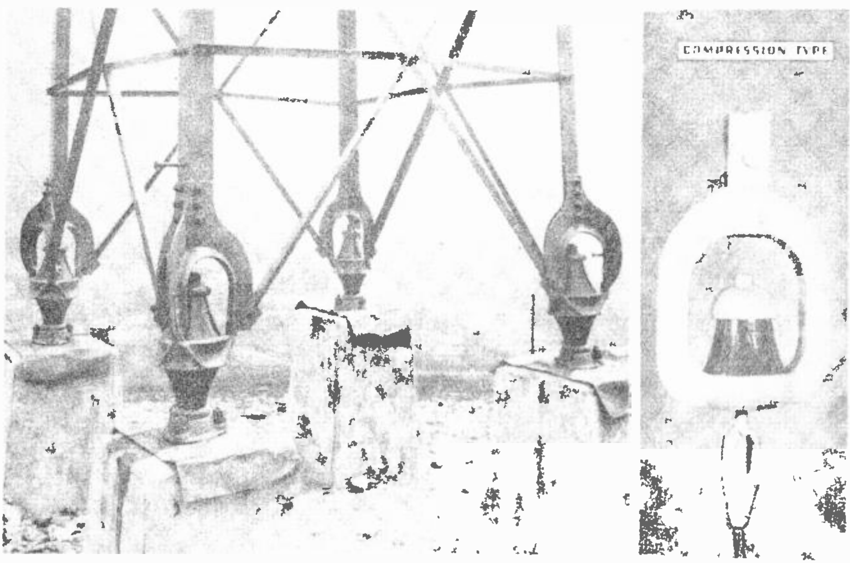


Fig. 60 Base insulators and guy insulators for vertical radiators.

Fig. 60 pictures a close-up of the base insulators for a self-supported tower and the guy insulators for a guyed tower. Notice that in all cases the load is carried in compression on the insulator. In the case of the tower leg insulators, the downward weight is carried on one-half of the insulator, while any uplift is transmitted as compression on the other half of the insulator by the bolt running up the center of the insulator.

14. THE GROUND SYSTEM. The reason that a current flows in an antenna is due to the fact that various capacities exist between the antenna and ground, and this current is the charging current of these numerous capacities. In order to charge these capacities, a current will have to flow from the base of the tower out through

the ground. Thus, a large circulating R.F. current will be flowing in the earth all around the base of the tower, and this current will be appreciable for a distance of one-quarter to one-half wave length in all directions from the tower's base. The soil is not a perfect conductor, and this charging current will encounter a certain amount of resistance in flowing through the ground. Some soils are better in this respect than others, however, to insure that the charging current which flows through the ground does not encounter much resistance and thereby introduce losses, it is usual practice to increase the ground conductivity by means of a ground system. This ground system consists of radial wires extending outward in all directions from the base of the tower. To protect these wires from mechanical injury, they are ordinarily buried several inches below the surface of the earth. All of these radials join at a common point which is immediately under the base of the tower. To increase further the earth's conductivity immediately under the base of the tower, a ground screen is sometimes provided. This should extend slightly beyond the base of the tower, and the radials may be soldered to it if desired.

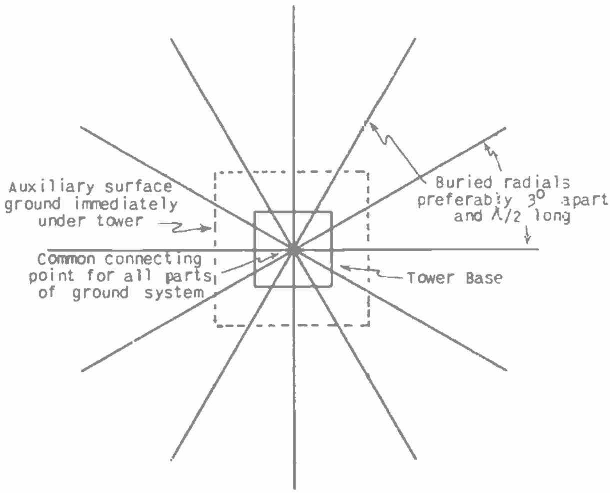


Fig.61 Ground system for a vertical reflector.

Fig. 61 shows the ground system which is usually employed with modern antenna installations. To be the most effective, the radials should be one-half wavelength long, and in no case should they be shorter than a quarter-wavelength. At least 60 radials should be used, and better results will be obtained with as many as 120. In no case should the radials be buried deeper than a few inches. If they are, the capacity between the antenna and the ground will have a composite dielectric consisting of the air and the several inches of earth, and the soil will have a high dielectric hysteresis loss.

Thus, the radials should be buried no deeper than sufficient to provide them protection.

To reduce hysteresis losses, it is very desirable to have the area adjacent to the transmitting tower free from foreign objects such as trees, posts, or buildings. Thus, fewer losses will be experienced if the tower is not located immediately adjacent to the transmitter building, but is coupled to the transmitter by means of a buried concentric line.

15. TOWER LIGHTING. It was early recognized that there was a definite need for painting and lighting an antenna tower so that it would not constitute a serious hazard to air navigation. By painting the alternate sections of the tower two contrasting colors, its visibility by day is very much intensified. For maximum visibility, the tower should be painted throughout its height with alternate horizontal bands of international orange and white, terminating with orange bands at both top and bottom. The width of the orange bands should be one-seventh of the height of any structure less than 250 feet, and between 30 and 40 feet for towers over 250 feet high. The width of the white bands should be one-half of the orange bands.

For towers up to 125 feet in height, the following lighting system shall be used: at the top of the tower there shall be placed two 100-watt traffic signal type lamps. At least one of these lamps must burn continuously between dusk and dawn. When only one lamp burns continuously, the circuit must be equipped with a change-over relay that will immediately throw the spare lamp into the circuit in case of burn-out of the first lamp. At both the one-third and two-third levels, two 100-watt traffic signal lights shall be installed one on each of the two opposite corners. Naturally, if the cross section of the tower is triangular, this regulation must be modified, but the lights must be so placed that there will be one visible at each level from any point of view. All of the lamps must be enclosed in red holophane globes and shall burn from dusk to dawn.

Higher towers require more lighting, and particularly hazardous locations near airlanes require additional illumination. A red airway hazard beacon of the flashing variety may be required; or 24-inch 1000-watt rotating marker beacons. In any event, each particular installation must be approved by the Federal Communications Commission.

As much as four kilowatts may be required for tower lighting and it is somewhat of a problem to transfer this 60-cycle AC power to the radiator. In the majority of cases, the tower is insulated from ground, and therefore is at a R.F. potential with respect to ground. Any wire installed to carry lighting power would be inductively coupled to the tower, and the R.F. voltages induced in the power wires would be fed back into the power line as well as placing a severe radio frequency load on the transmitter.

Commercial chokes are available which are capable of isolating R.F. potential up to 10,000 volts at broadcast frequencies. These chokes are inserted in series with the leads which carry the lighting power to the tower. The ends of the chokes which are connected to the power source are bypassed to ground and, in addition, there is sometimes included an isolating transformer connected between the power lines and the filter. The filter consists of the bypass condensers and chokes, and this whole assembly is mounted in a weatherproof case which is placed on top of a pole near the base of the antenna. Fig. 62 shows this arrangement as well as a three-circuit installation with a transfer relay to supply power to the spare lamp, in case the first lamp burns out.

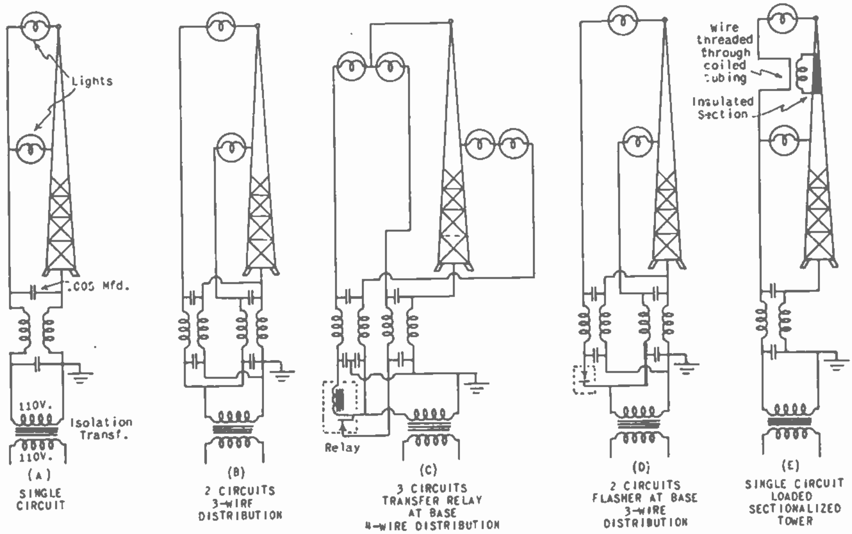


Fig.62 Tower lighting circuits.

The problem of efficiently transferring the radio frequency power from the transmitter to the antenna includes a discussion of all types of transmission lines as well as coupling networks and tuning procedure. This subject will be covered in a later lesson which also includes methods of measuring radiation resistance of antennas and of measuring the field strength produced by a particular installation.

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POWER & LIGHT BUILDING, KANSAS CITY, MISSOURI

UNIT NO. 4

LOW-POWERED TRANSMITTERS

LESSON NO. 7

TOMORROW BECKONS

.....the man who seeks success.

It is of the utmost importance to you Mr. Student that you watch your viewpoint with care. Never let it "grow old", even though you yourself become older with the passing of the years. The young man with the young viewpoint is at all times alert to new developments that offer future opportunity. He prepares for the coming of new industries in advance, so that when they arrive he is ready to reap the golden rewards. The older man with a young viewpoint, sees promising new developments in their true light. He never permits his mind to reach the point where he believes that certain things are impossible. Consequently, he too is always prepared for new industries that are created by the master minds of brilliant scientists.

Think of the world that we might be living in today were it not for the fact that scientists are continually striving for new accomplishments.....and if it were not for the fact that men and women were not being continually beckoned by tomorrow. The steamboat, railroad, airplane, automobile, radio, and television are possible only because the human race is continually on mental tiptoe. Tomorrow calls as it never did before. But unfortunately only the alert, the ambitious members of the human race, such as yourself, are preparing themselves to answer the call.

And so that you may fully realize the importance of the training that you are securing under the supervision of Midland engineer-instructors, we want to sound a clarion call that we know you will heed. Stick to your guns..... your training, and whenever discouragement stands in your way, take a fresh grip on yourself and remember.....that tomorrow beckons you.....a golden tomorrow, rich in the pleasures of life.....a tomorrow that can bring you the fulfillment of your fondest dreams and ambitions.

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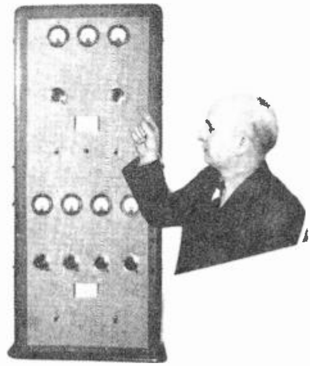
Lesson Seven

LOW-POWERED TRANSMITTERS



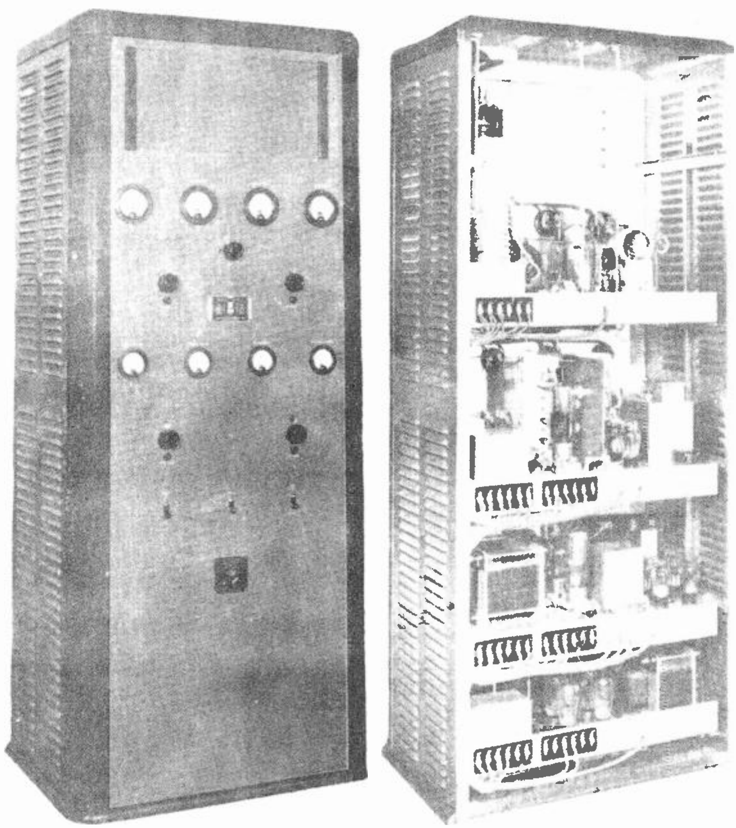
"It is the purpose of this lesson to acquaint you with the design and construction of actual commercial type low powered transmitters. This information will enable you to become familiar with practically any type of transmitter which you might encounter in going on the job with some broadcasting station.

"Study this material thoroughly because you can never tell how soon you might need it".

1. LOW-POWER RCA TRANSMITTERS. The RCA Manufacturing Co. has recently introduced two models in the low-power transmitter field, namely the 100-G/250-G and the 100-H/250-D. These may be classified as the "economy" and the "deluxe" models, respectively. The 100-G/250-G has been designed with emphasis on the necessity of providing high-quality operation at a minimum cost. The performance of this latter transmitter is on a par with the deluxe model, the economy being obtained by elimination of certain decorative and convenience features. The mechanical design of the 100-G/250-G is as simplified as it can be made, the controls and meters are mounted on the front panel, and access doors are limited to a single rear door. On the other hand the 100-H/250-D deluxe model is more complicated in mechanical construction, front access to the tubes is provided, meters and tuning controls are grouped on recessed panels, and provisions are incorporated in the control and output circuits so that they may be inter-connected easily with larger units which may be added later. The economy transmitter is intended for strictly local stations, licensed for 100 watt or 100-250 watt operation. The deluxe model is intended for those 100-250 watt stations where a future increase in power is likely. The front panel of the deluxe model is designed the same as the 1 kw. and 5 kw. amplifiers so that these units may be added at a later date without disrupting the harmony of the transmitter's appearance. We shall discuss the economy transmitter (100-G/250-G) briefly, then proceed into more detail concerning the deluxe 100-H/250-D.

In discussing the Deluxe 100-H/250-D Transmitter we will consider its use in securing either 100 or 100/250 watts output. When used as an exciter unit for the RCA 1,000, 5,000 or 50,000 watt transmitters some changes are necessary, depending on which type of power amplifier it is used with. These changes will be discussed in connection with these transmitters in following lessons. In studying these transmitters it is advisable to check the characteristics of the various tubes used. Ascertain for yourself if the tubes are being operated under maximum or minimum conditions.

Study the wiring diagrams carefully so that you will have a thorough knowledge of the operating principles of each transmitter. Inspection of the diagrams will reveal that where two wires cross but do not connect, no jumper has been drawn. When a connection is intended, a dot is placed at the junction. Watch this carefully.



(A) (B)

Fig.1 Photograph showing front view of the RCA 100-G/250-G Broadcast Transmitter. (B) Rear view of the same transmitter.

THE RCA 100-G/250-G

Introduction. Front and rear views of this transmitter are shown at A and B, respectively, in Fig. 1, The mechanical design of the transmitter features a horizontal chassis layout, all of the components except the controls and meters are mounted on four easily removed chassis shelves. Referring to B in Fig. 1, the panels from bottom to top are the rectifier, the audio and modulator stages, and oscillator, buffer and intermediate stages, and the power amplifier stage and output coupling system. The circuit diagram of the 100-G/250-G, is shown in Fig. 2. The transmitter is called "Model 100-G" when it is used for 100 watt operation, and is specified as the "Model 250-G" when used as a 250 watt or 100/250 watt transmitter.

The 100-G transmitter uses RCA 838's in the intermediate power amplifier (I.P.A.), power amplifier, and modulator stages with 1,000 volt plate supply. The 250-G transmitter uses RCA 805's in the intermediate power amplifier, power amplifier and modulator, with a 1250 volt supply. A relay which reduces the plate voltage on the power amplifier, is provided for day-night operation on 100 and 250 watts.

The transmitter is a complete unit requiring only the connection of antenna, ground, power supply, and audio input. The antenna tuning equipment and antenna ammeter will meet almost all requirements. The transmitter may be adjusted to any frequency between 550 and 1600 kc. with the tapped coils and variable condensers without the use of any extra equipment. The transmitter is designed for an audio input of approximately 0 level (12½ milliwatts at 500 ohms); a potentiometer is provided to obtain the proper adjustment.

An opening is provided on the front for a modulation monitor standard 8¾" panel. The transmitter is normally furnished with a blank panel, gray finish, but may be ordered with a modulation monitor.

A special feature of this transmitter is the frequency stability obtained with the V-cut, low temperature coefficient crystal. The complete oscillator unit, including crystal holder and oven, oscillator tube and vacuum type thermostat, is arranged with a plug-in type mounting. No tuned circuits are used in the oscillator and the output is effectively electron-coupled to the plate or output circuit of the tube. It is recommended that the equipment include two crystals mounted in their proper holders, one of which is installed in the oscillator unit and the second plugged into the socket provided for a spare. This arrangement provides for maintaining a spare crystal at constant temperature.

Referring to the front view of the transmitter in Fig. 1, the lowest control on the panel is the audio frequency input attenuator. Directly above and from the left to the right are, the filament power switch, the high-low power switch, and the plate power switch. Above the switches are the tuning controls for the buffer stage and the intermediate power amplifier. Neutralization of the intermediate power amplifier is accomplished by means of a wrench supplied to fit the hexagonal socket midway between the dials. The row of small meters indicate the crystal plate current, the buffer

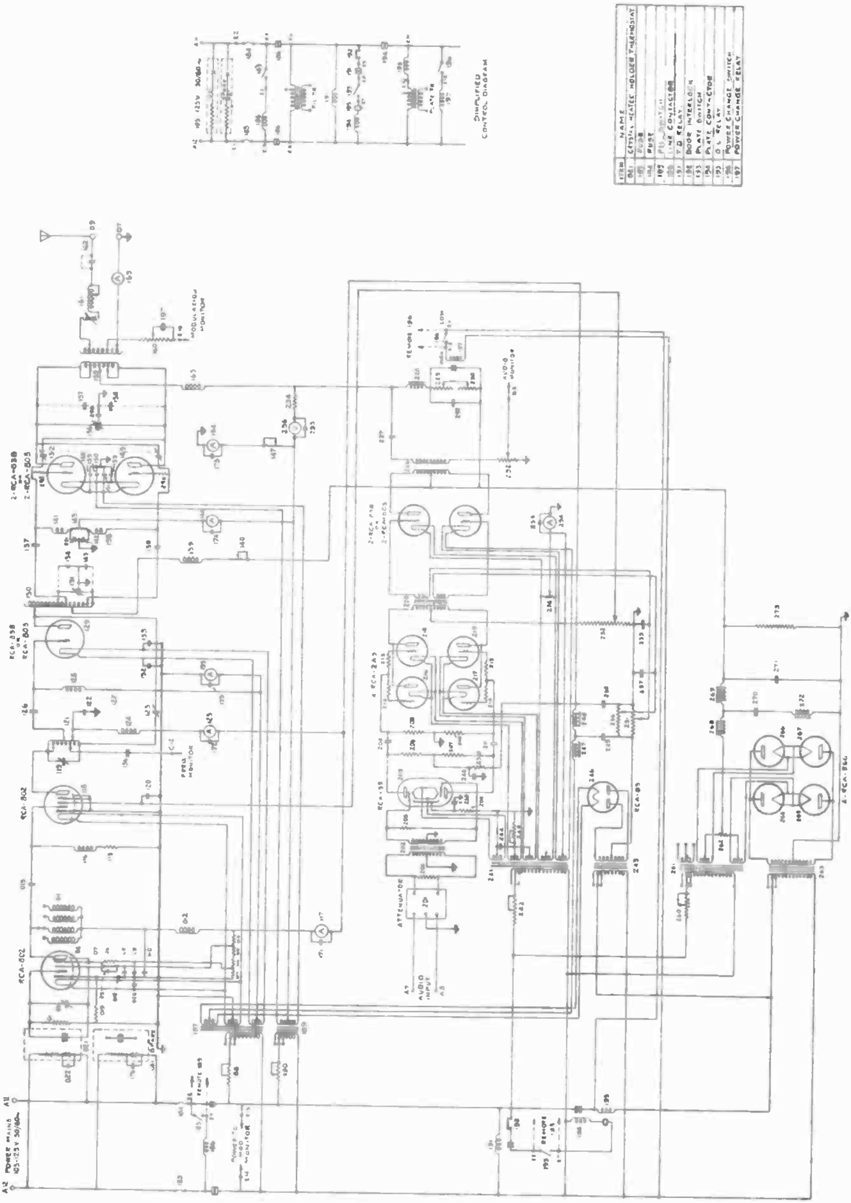


Fig.2 Schematic diagram of the RCA 100-G/250-G Broadcast Transmitter.

plate current, the intermediate power amplifier plate current, the modulator plate current. Above the small meters are the dials for power amplifier plate circuit and antenna tuning. The hexagonal socket for adjusting the power amplifier neutralizing is located midway between these dials. A control is provided on the front panel for fine adjustments of the power output. The row of large meters indicates the power amplifier grid current, power amplifier plate voltage, power amplifier plate current and antenna current. The final plate current and plate voltage meters meet the requirements of the F.C.C. in measuring the power input.

TUBE COMPLEMENT

TYPE 100-G TRANSMITTER (100 WATT OUTPUT)

Oscillator	1 - RCA-802
Buffer	1 - RCA-802
Intermediate Power Amplifier	1 - RCA-838
Power Amplifier	2 - RCA-838
Speech Amplifier	1 - RCA-53
Class A Drivers	4 - RCA-2A3
Class B Modulators	2 - RCA-838
High Voltage Rectifier	4 - RCA-866
Low Voltage Rectifier	1 - RCA-83

TYPE 250-G TRANSMITTER (100/250 WATT OUTPUT)

Oscillator	1 - RCA-802
Buffer	1 - RCA-802
Intermediate Power Amplifier	1 - RCA-805
Power Amplifier	2 - RCA-805
Speech Amplifier	1 - RCA-53
Class A Drivers	4 - RCA-2A3
Class B modulators	2 - RCA-805
High Voltage Rectifier	4 - RCA-866
Low Voltage Rectifier	1 - RCA-83

Remove plate caps above the RCA-838 tubes as they are not used in the Type 100-G Broadcast Transmitter. These caps are used only in the Type 250-G Broadcast Transmitter on the RCA-805 tubes.

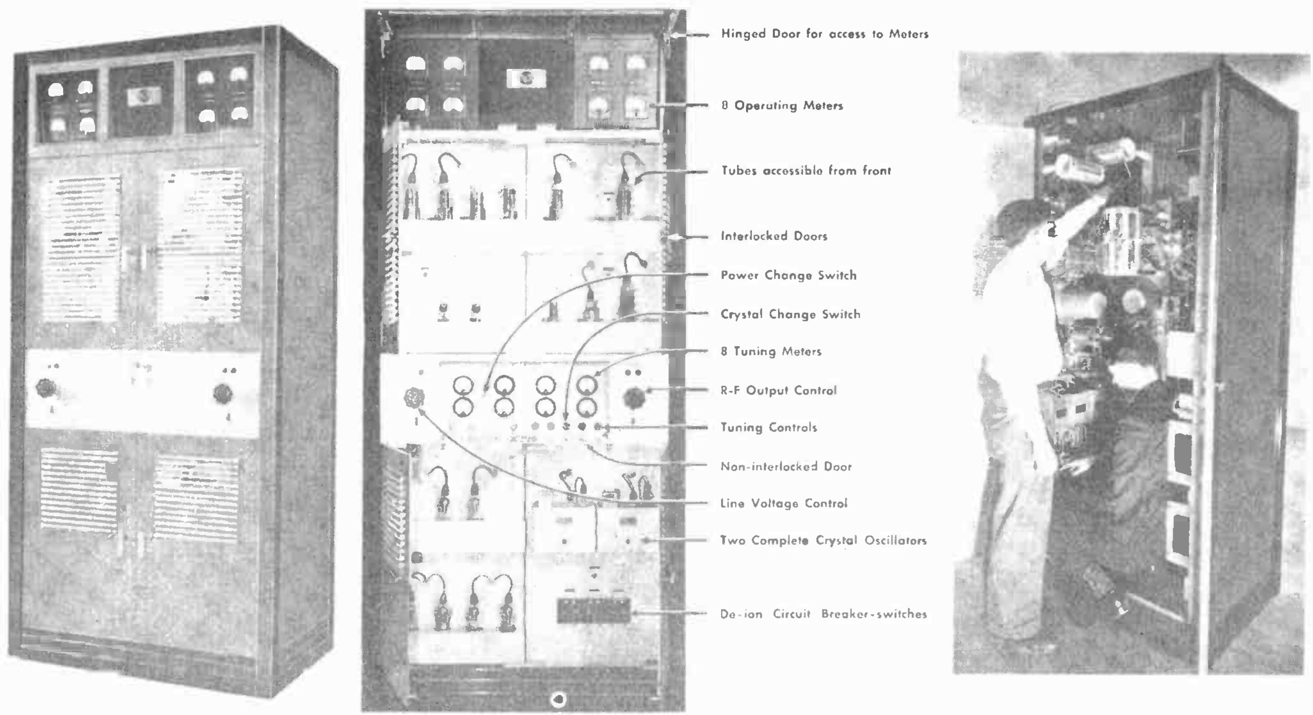
Fig. 3.

The output coupling system is designed to match either an open type or concentric transmission line, or to feed the antenna directly. There is a space at the top of the transmitter panel into which any standard type modulation monitor may be mounted. So mounted, the monitor becomes practically a part of the transmitter. In smaller stations, this is convenient, in that it places the modulation monitor in the best position for observation.

The tube complement for operating this equipment as a 100-watt or 250-watt transmitter is shown in Fig. 3.

THE RCA 100-H/250-D DELUXE TRANSMITTER

Front and rear photographic views of this transmitter are shown in Fig. 4 and a complete wiring diagram in Fig. 5.



(A) (B) (C)

Fig.4 (A) Photograph showing front view of the RCA 100-H/250-D Broadcast Transmitter. (B) Front view of same transmitter with doors open. (C) Rear view with doors open, showing accessibility of parts.

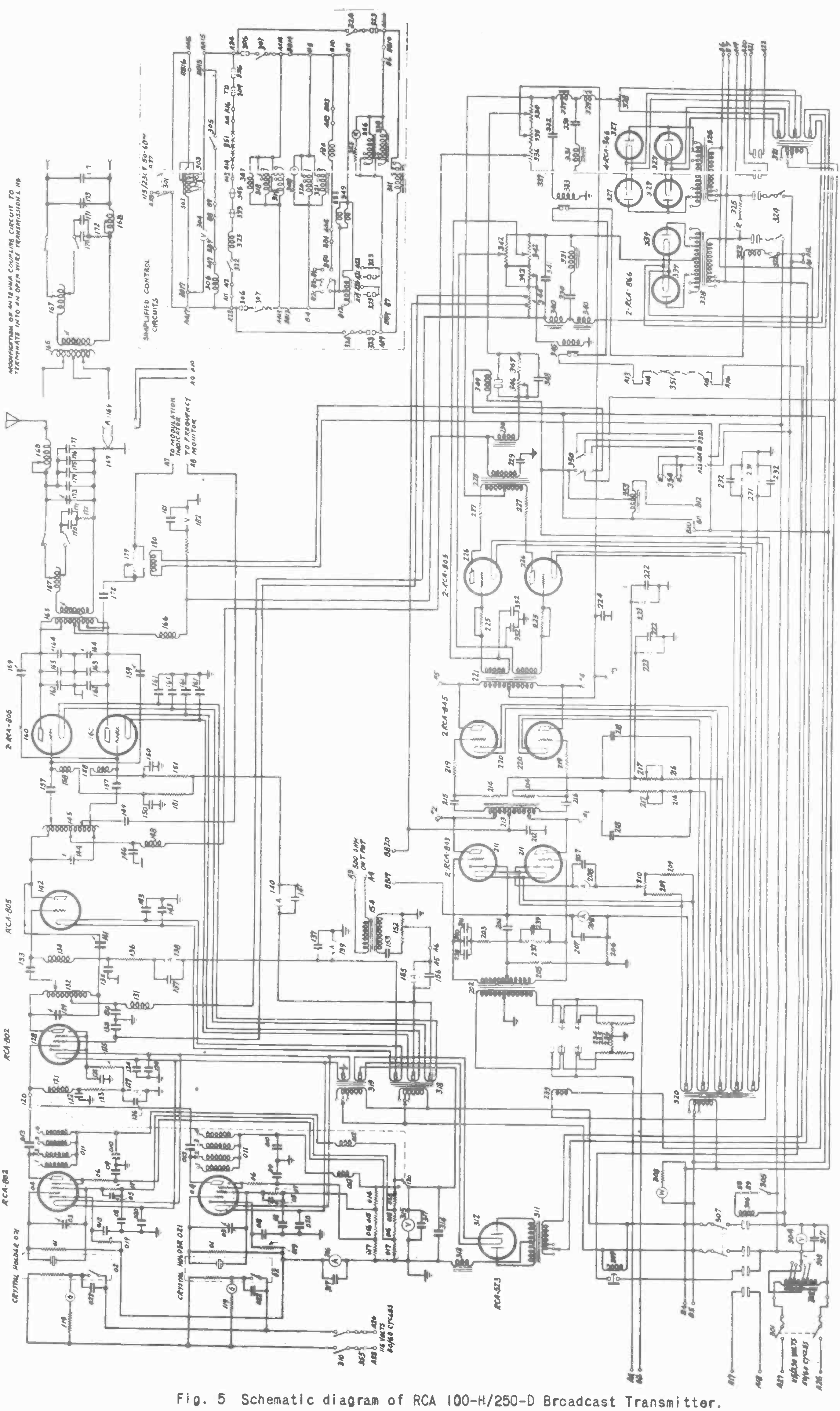


Fig. 5 Schematic diagram of RCA 100-H/250-D Broadcast Transmitter.

(A) Introduction. This broadcast transmitter is designed for high fidelity, low distortion, low carrier noise and reliability of operation. It may be operated at 100 watts, 100/250 watts, or 250 watts output with the tube complement specified in Fig. 6.

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
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

Fig. 6.

The transmitter is normally wired for 250 watt operation (250-D). It will be necessary to make a few wiring changes before operating at 100 watts (100-H). Instructions for making these changes will be found under "Installation".

Both types, 100-H and the 250-D transmitters, utilize the same tube complement in their oscillator and buffer stages. The 100-H type utilizes one RCA-838 tube in the intermediate power amplifier (I.P.A.), two RCA-838 tubes in the power amplifier (P.A.) and four RCA-845 tubes, operated Class "A" as the modulator with 1050 volt plate potential. The type 250-D transmitter 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. A relay, operated by a switch on the control panel, connects or short circuits dropping resistors for the 100/250 watt operation, thus reducing the P.A. plate voltage for 100 watt operation. The control panel switch also operates relays which maintain the audio input level and output AF voltage constant for proper modulation.

The transmitter is designed for operation 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 any type antenna normally used with broadcast transmitters. In unusual cases it may be necessary to substitute an antenna ammeter with a different scale range. Terminals are also provided which are suitably arranged for supplying energy for operation of a modulation monitor, a frequency monitor, and for audio monitoring.

Using a constant tone source, (12.5 milliwatt reference level) the audio input level for the 250-D, (250 watt) transmitter is approximately -6 db at 100% modulation with no input attenuation. The 100-H, 100 watt transmitter input level is approximately -2 db at 100% modulation with no input attenuation. With average program modulation, the power input is approximately 1400 watts for the 100-H transmitter and 1700 watts for the 250-D.

The assigned frequency of this transmitter will be maintained within the limits of plus or minus 10 cycles for either of the UL-4292 crystal oscillators incorporated in the transmitter, together with a "V" cut crystal mounted in a TMV-129V compensated, temperature-controlled holder. A switch on the control panel is provided for the selection of either unit.

The 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 plate circuit. 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 and an audio unit. Referring to front view illustration at B, Fig. 4, the four lower tubes on the left side (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 amplifier tubes are located on the third shelf. The fourth or top shelf supports the modulator tubes in the 100-H transmitter or the driver and modulator tubes in the 250-D. Meters for indicating the line and plate voltages and currents are located on the top meter panel of the audio section. Meters for indicating the plate currents of the audio tubes are located on the control sub-panel together with the potentiometers for adjusting the bias of the audio system. The line voltage adjustment and filament control switch 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 overload and line switches. Directly above these are mounted the two crystal oscillator units. Located on the first shelf is the oscillator plate voltage rectifier, the buffer and I.P.A. tubes and on the second shelf the power amplifier tubes. The control sub-panel contains the meters for indicating the plate and grid currents for buffer, I.P.A. and P.A. tubes, crystal oscillator selector switch and tuning controls for the buffer, I.P.A., P.A. and antenna tuning. On the main control panel is 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 power amplifier and intermediate power amplifier neutralizing capacitors are adjustable through the grille bars.

(B) Circuits. The schematic diagram of the 250-D transmitter shows the electrical items and terminal markings. The 100-H and 250-D are similar except for the audio system and tube complements.

The crystal oscillator utilizes an RCA-802 tube with the crystal connected between the control and screen grids. The plate circuit consists of four chokes, (Item 011) each designed for a certain frequency band as specified below.

Coil No.	Frequency Band
4	550 - 700 KC
3	700 - 1150 KC
2	1150 - 1400 KC
1	1400 - 1600 KC

The crystal is adjusted in a similar oscillator before shipment, and it is only necessary to select the proper coil connection and adjust the circuit to zero beat as indicated by the frequency monitor, with the vernier condenser, (Item 03).

The crystal oscillator plate and grid voltages are obtained from the single phase full wave rectifier utilizing an RCA-5Z3 tube. No plate voltage is applied to the spare oscillator.

A separate 115 volt supply is connected to the terminals A25 and A26 at all times to maintain both crystals at the proper operating temperature. Meters, (Items 315 and 316), indicate the plate voltage and plate and screen grid currents of the operating oscillator. Signal lights indicate proper operation of the heater circuits.

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. The plate and screen voltages are obtained from the low voltage rectifier.

The intermediate power amplifier utilizes an RCA-805 tube in the 250-D and an RCA-838 tube in the 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 is obtained from the high voltage rectifier.

The power amplifier consists of two RCA-805 tubes in the 250-D and two RCA-838 tubes in the 100-H transmitter. This stage is cross-neutralized. Taps are provided on the power amplifier tank coil to obtain voltages for the modulation indicator.

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 consists of a "T" network, and is used when the transmitter is connected to an antenna, or an open wire transmission line. When a concentric line is used, the coupling coil is connected directly.

Meters, (Items 182 and 155), indicate power amplifier plate voltage, and current. Item 169 indicates antenna current. This antenna ammeter 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 indication of antenna currents to one-fifth of the maximum scale reading, has been approved by the Federal Communications Commission.

The audio system of the 250-D consists of 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 for reading the plate current of each tube are provided in the tube cathode circuits, (Items 208).

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, (Item 217). The plate voltage is supplied by the high voltade rectifier. Plate circuit milliammeters for each tube are provided, (Items 223).

The bias voltage of the modulator tubes is supplied by the low voltage rectifier, and each tube may be adjusted, by means of potentiometers, (Item 342), located on the control sub-panel. The plate voltage is supplied by the high voltage rectifier.

The audio system of the 100-H transmitter, consists of two RCA-845 tubes, operated Class "A", in the first audio stage, and four RCA-845 tubes operated Class "A", as modulators. Separate meters, (Items 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 each pair of tubes may be adjusted by means of potentiometers, (Item 342) located on the control sub-panel.

The input level of the 250-D transmitter is approximately -6 db and that of the 100-H transmitter approximately -2 db. (The input level of the audio system may be increased 14 db, in 2 db steps, by means of the fixed pads; Items 234, 235, and 236). The audio monitor transformer, (Item 154) delivers an output of approximately zero level into a 500 ohm impedance load, at 100% modulation (250 watts output).

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 stages, and grid bias for the modulator tubes.

The high voltage rectifier utilizes 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.

Both rectifiers utilize two section filters to reduce the ripple to a minimum and have a regulation of less than 5%.

The overload switch, (Item 301) controls the power supply to entire transmitter and also protects the equipment in case of ort in the power supply line within the transmitter. The trans- er is started by means of the master control switch, (Item 305) ed "FILAMENT" and located on the main control panel. By op- ng this switch, the filament contactor, (Item 306) is energized loses its contacts, thereby energizing the time delay relay, 309) and all filament transformers which are protected by the oad. At the end of 30 seconds, the time delay relay contacts, are in series with the plate contactor coil, (Item 323), plate , (Item 322), and door "interlock" switches, (Item 351), close. sing the doors and operating the plate switch marked "PLATE", ate contactor operates and energizes the oscillator plate rectifier, low and high voltage rectifiers. The overload (Item 324), protects the RCA-866 rectifier tubes in case erload. If, for any reason, the low and high voltage recti- e overloaded, the overload relays, (Items 345 and 333) will and de-energize the plate contactor.

line voltage may be controlled within close limits by means to-transformer, (Item 302) and tap switch, (Item 303), lo- the main control panel.

crystal heater circuit is protected by the fuses, (Item

Installation.

NG: OPERATION OF THIS EQUIPMENT INVOLVES THE USE OF HIGH VO NGEROUS TO HUMAN LIFE. THE OPERATING PERSONNEL MUST AT AL OBSERVE ALL SAFETY REGULATIONS. DO NOT CHANGE TUBES OR MAI MENTS INSIDE THE EQUIPMENT WITH PLATE VOLTAGE ON. DO NOT WITH THE DOOR INTERLOCK SYSTEM.

cation of the transmitter should be carefully selected in make the antenna lead-in and ground connections as short as There should be sufficient air circulation so that the temperature will not exceed a maximum of 110° F. The tran should be accessible at the sides and rear to simplify maintenance.

Three coils, (Items 165, 167 and 168) of the equipment, are packed separately for shipment. When making the installation, these coils are easily reassembled with their mounting insulators in their positions on the upper portion of the R.F. chassis. Coil, (Item 168) mounts horizontally at the top of the chassis above the square hole located behind the meter panel. Coil, (Item 167) mounts horizontally on the side of the chassis above the power amplifier tank capacitors. Coil, (Item 165) mounts with its axis vertical, on the front part of the chassis behind the central power amplifier tube, Mounting holes are properly positioned in the chassis and mounting screws, nuts and washers are packed with the coils. The permanent connections to the coils are tagged in duplicate showing their proper locations. Attach the flexible shaft to the insulating coupling of the rotor of Item 165, by the set screw provided and secure the shaft casing to its supporting post.

The buffer and I.P.A. shielded tank coils, (Items 134 and 145) are clamped to the chassis by wooden blocks during shipment. These blocks and their supporting studs should be removed at installation.

The large shield which has been arranged to enclose the upper portion of the R.F. chassis, is also 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 are located centrally in the equipment, on the edge of the chassis, facing the rear. The other set is located on the rear edge of the chassis, facing the center of the unit.

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. A lightning protection switch or horn type safety gap should be installed 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 good connection.

For either the 100-H or 250-D transmitter, arrange the antenna circuit connections to suit the antenna terminating system to be employed.

A 115 or 230 volt, 50 to 60 cycle single phase, power supply, having a regulation of 5% or better should be connected with No. 12 B & S gauge, insulated wire to the transmitter terminals A-27 and A-28. It is recommended, and usually required by local authorities, that a fused line switch be provided.

The auto-transformer, (Item 302), should be correctly connected for the supply voltage used. The center tap is used for 115 volts and the outside tap for 230 volts. Make certain that the switch, (Item 301) is open before the power leads are connected.

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 AC supply.

Wire No. 19 twisted pair, rubber-covered and lead sheathed should be used for all external audio connections.

The audio input leads should be connected to terminals A-1 and A-2 and the audio monitor leads to A-3 and A-4.

The frequency monitor connection should be made to terminal A-8 and the modulation indication connection to terminal A-7, with shielded low-capacity cable.

The 100-H and 250-D transmitters use different audio systems. The equipment is normally shipped with connections in place for operation as a 250-D unit. For operation as either 100-H or 250-D equipment, arrange the circuit connections on the audio chassis to suit the required operation.

The filament and plate voltages may be remotely controlled by connecting switches to terminals B-8 and B-9, and A-11 and A-12, removing the jumper wires that are normally in place shorting these terminals.

The time delay relay, Item 309, should be adjusted so that its contacts close approximately 30 seconds after the "Filament" switch has been operated. The dashpot should be filled with oil. The operating time may be varied by adjusting the depth of the plunger, or varying the number and size of holes in the plunger cup, by turning the disc located in the bottom of the cup.

Adjust the length of the plungers of the overload relays for the following values:

	Relay Item 333	Relay Item 345
250-D	1.4 Amps.	.8 Amps.
100-H	1.2 Amps.	.8 Amps.

The high and low voltage plate transformer secondary connections should be made as follows:

	Transformer Item 326	Transformer Item 338
250-D	Terminals 2 and 2	Terminals for 1290 volts
100-H	" 3 and 3	" " 1620 volts

The shorting jumper on the resistor, Item 343, should be connected in the 100-H transmitter so that the total resistance is 580 ohms. By using the 540 or 620 ohms tap, the bias voltage may be changed by ±10 volts if the transformer voltage is not correct.

Check the crystal oscillator to make certain that the proper plate coil is used for the particular frequency, as specified in the table under "CIRCUITS". It is necessary to remove the output terminal nuts, in addition to cover screws, in order to remove the cover.

Open the switch, Item 324, in order that no plate voltage may be applied, and remove all tube plate caps. Adjust the line voltage switch for 115 volts. On initial operation of the filament switch, allow the tube filaments to heat 30 minutes, as this precaution will increase the life of the 866 tubes. All filament voltages should be within ±2% of their ratings.

Replace the crystal oscillator tube caps, operate switch, Item 324, and apply plate voltage to the crystal oscillators by operating the switch marked "PLATE". The voltmeter, Item 315, should indicate 330 ±10 volts. Adjust the oscillator selector switch, Item 120, to both positions to make certain each crystal oscillator is operating properly. The oscillator plate current should be within the limits specified in the "Table of Typical Meter Readings". (Fig. 7).

Replace the tube caps on the low voltage rectifier tubes, operate the "FILAMENT" and "PLATE" switches. Check the operation of the door interlock switches by opening and closing the doors.

Resonate the RCA-802 buffer stage by adjusting the variable capacitor for a minimum indication of the plate current meter, Item

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 Item 344.

Also, adjust the plate voltage of the first audio tube for 400-425 volts.

Adjust the taps on I.P.A. tank coil as follows:

	550-1000 KC	1000-1600 KC
I.P.A. Capacitor taps	P-1 - P-1	P-2 - P-2
P.A. Grid taps	G1 - G1	G2 - G2
Center tap	C2	C2

The taps C1 and C3 (not shown on Fig. 5.) are off center slightly and are used to balance the power amplifier tubes in order that they may have equal grid currents in cases where they are out of balance by 10% or more.

TYPICAL METER READINGS

	250-D 100 W	250 W	100-H 100 W
Line Voltage	115	115	115
Oscillator Plate Volts	330 ±10	330 ±10	330 ±10
Oscillator Plate Current	20 ±5	20 ±5	20 ±5
Buffer Plate Volts	480	480	480
Buffer Plate Current	45-55	45-55	45-55
Buffer Screen Volts	200-230	200-230	200-230
IPA Plate Volts	800-1000	800-1000	800-1000
IPA Plate Current	75-110	75-110	75-110
IPA Grid Current	30-40	30-40	30-40
PA Grid Current	100-110	100-110	100-110
PA Plate Current	210-215	335-340	200
PA Plate Volts	780-790	1250	1000
First Audio Plate Volts	415-420	415-420	415-420
First Audio Plate Current/tube	20-25	20-25	20-25
Second Audio Plate Volts	1225	1225	
Second Audio Plate Current			
Left	50-55	50-55	
Right	50-55	50-55	
Modulator Plate Current			
Left (no mod.)	35-45	35-45	65 (per tube)
Right " "	35-45	35-45	65 (per tube)
Modulator Plate Volts	1320	1320	1050

FIG. 7

Replace the I.P.A. tube cap and resonate the tank circuit by adjusting the variable capacitor, Item 144, for a minimum indication of the plate current meter, Item 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 900 volts by changing the connection on the resistor, Item 336.

Neutralize the I.P.A. stage by adjusting the neutralizing capacitor, Item 141, for a minimum or zero power amplifier grid current. At the higher broadcast frequencies, the I.P.A. may neutralize better by selecting taps C1 and G1 instead of taps C2 and G2 (not shown on Fig. 5.) normally used.

The proper voltage for the frequency monitor is obtained from taps T1 or T2.

Replace the tube caps on the high voltage rectifier tubes, power amplifier tubes 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.

Adjust the turns of the power amplifier, apply plate voltage and resonate the tank circuit by adjusting variable capacitor, Item 164, for a minimum indication of the plate current meter, Item 155.

The power amplifier may be neutralized by connecting a 0-115 ma. thermo-galvanometer, or 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, then adjusting the neutralizing capacitor for a minimum indication of the same meter.

With minimum coupling to the antenna, the plate current of the power amplifier tubes should be kept low as the tubes are unloaded. As the antenna circuit is closer coupled to the power amplifier tank coil, increased power is drawn from it, resulting in an increase in the amplifier plate current.

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. Both series arms are inductive, Items 167 and 168, and the parallel section is capacitive, Items 173-177.

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 and antenna coupling circuit has been tuned and loaded, adjust the plate voltage 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 of the audio tubes then readjust the power amplifier plate voltage.

With the power change switch in the "100 W" position, adjust the tap connection on the resistor, Item 346, until the following meter readings are obtained:

P.A. Plate Voltage	780-790 volts
P.A. Plate Current	212-215 ma.
P.A. Input	167.5 watts

The 100/250 operation 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 the "R.F. OUTPUT" control, Item 165, if for any reason the antenna resistance varies and changes the transmitter load or the power amplifier plate voltage does not remain constant.

In the 100-H transmitter, the power change switch should be left in the "250 W" position. (Except during tuning adjustments.)

The correct voltage to the modulation indicator for the 250-D transmitter should be selected with the power change switch in the "100 W" position, by adjusting the taps on the power amplifier tank coil. Then throw the power change switch to the "250 W" position, and adjust the resistor, Item 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, Item 210. A harmonic analyzer or indicator should be used and tuned or adjusted to the fundamental hum frequency, i.e., 50 or 60 cycles. Then adjust the hum potentiometer for a minimum indication.

If a line amplifier is used in connection with the transmitter, it is usually desirable to add audio input attenuation at the transmitter, Items 234, 235, 236, thus increasing the amplifier output level and also the signal to noise ratio of the amplifier.

When the 250-D transmitter is operated 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 reduce the audio input level, the 2 db pad, Item 234, is arranged so that it will be connected or disconnected by the relay, Item 233, which is controlled by the power change switch.

To keep the distortion at a minimum in the 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. Connect the capacitors, Items 170 and 171, as follows:

Frequency KC	Capacitor Connection
550-830	.0003 mfd. and .0002 mfd. (Parallel connection)
830-1150	.0003 mfd.
1150-1500	.0002 mfd.
1500-1600	.0003 mfd. and .0002 mfd. (Series connection)

Adjust the tap connection on the coil, Item 167, until the circuit consisting of the coil, Item 167, antenna coupling coil, Item 165, and capacitors, Item 169 and 171 are 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, the coupling coil position remaining fixed.

After the transmitter has been properly adjusted, connect an R.F. ammeter in the tank circuit and measure the tank current. As a 250-D transmitter, the proper value should be approximately 1.25 to 1.5 amperes. Adjust the turns on the power amplifier tank coil, retuning after each adjustment until the tank current is within the limit specified.

The I.P.A. plate voltage may be adjusted in order to obtain the proper power amplifier grid current.

(D) 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 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. A small blower may be used advantageously. The transmitter should be inspected periodically for loosened connections. As far as possible, anticipate tube failures by keeping a log and make the required tube replacements.

The contact surfaces on the relays and contactors should be cleaned periodically.

It is important that antenna insulators be kept clean to reduce high resistance ground leaks, which will decrease the radiation efficiency of the station. Also, clean the lightning protection switch contacts and tighten all ground and antenna connections.

COLLINS TYPE 300F BROADCAST TRANSMITTER

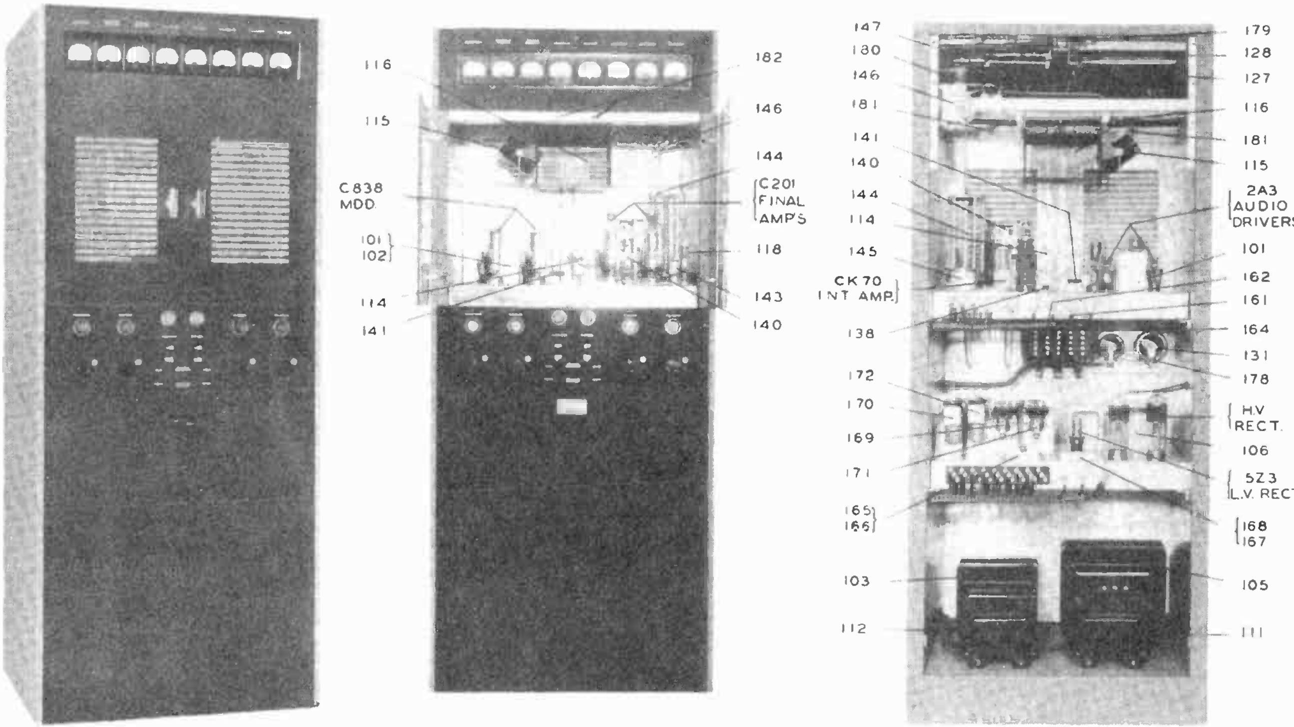
(A) DESCRIPTION.

General. The Collins 300F Transmitter has a power output of 250/100 watts and is designed for broadcast service. Among the desirable features included in the design of this transmitter is a new style cabinet which lends itself to any installation, straightforward electrical design, excellent workmanship, simplicity of installation and operation, reliability, freedom from necessity for technical observation, low power consumption, low tube cost and most important of all, high fidelity. Three views of the 300F transmitter are shown in Fig. 8.

The final stage of this transmitter is operated class "C", allowing full 250 watts output when operating according to indirect measurement of power. Furthermore, the transmitter is capable of being modulated 100% with audio harmonic distortion well below 5% r.m.s. or 10% arithmetic sum and the carrier shift well below 5%. High fidelity transmission is further insured by practically uniform frequency response from 30 to 10,000 cycles. High level plate modulation is used, resulting in a minimum of power consumption.

Use of the "HA" cut low temperature coefficient crystal in conjunction with an extremely stable oscillator circuit allows the operating frequency of the transmitter to be maintained within a few cycles of the assigned frequency and is capable of being maintained much closer than the plus or minus 50 cycles allowed by the Federal Communications Commission for this type of service.

This transmitter is designed for operating into a coaxial radio frequency transmission line of approximately 75 ohms surge impedance. The configuration of the output circuit is that of a low pass fil-



(A) (B) (C)

Fig.8 (A) Photograph showing front view of the Collins 300F Broadcast Transmitter. (B) Front view with doors open. (C) Rear view with doors open.

ter, insuring that the harmonic power transmitted to the antenna will be low and thus have very little radiation at radio frequency harmonics.

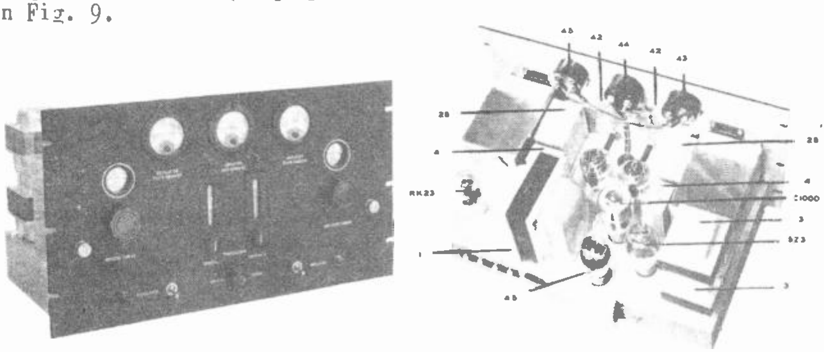
All circuits of the transmitter can be energized by conveniently located push button stations on the front of the transmitter. The relays controlling plate voltage are electrically interlocked with the filament relay so that no damage to equipment can result from improper application of power.

Separate meters are provided for all important circuits of the transmitter and for giving a continuous check on correct functioning of all components. To increase the number of circuits which can be metered for further checking the operation of the transmitter, some of these meters are arranged to be switched from one circuit to another by means of conveniently located key switches.

Power reduction is accomplished by switching a resistance into the plate circuit of the final r-f amplifier to reduce the input. In this way, the efficiency of the Class "C" stage remains constant. The residual carrier noise level is maintained more than 50 db below 100% modulation. Center tap adjustment is provided on the filament circuit of the final amplifier to adjust for minimum 60 cycle carrier hum.

The transmitter consists of two cabinets. These cabinets are designated as the 40D Frequency Control Unit and the 300F Amplifier and Modulator.

The 40D Frequency Control Unit is mounted in a 19" rack cabinet having dimensions of overall width of 20", overall depth of 14", and overall height of 42". This cabinet also has space for frequency monitoring equipment. Two views of the 40D unit are shown in Fig. 9.



(A) (B)

Fig.9 (A) Photograph showing front view of the Collins 40D Frequency Control Unit. (B) Photograph showing placement of parts in this unit.

The 300F Amplifier and Modulator consists of the intermediate and final radio frequency amplifier stages, the speech amplifier and class "B" modulator stages, in addition to the necessary power supply and control circuits. The 300F Amplifier cabinet is 30" overall width, 24" overall depth, and 72" overall height. A complete schematic of the 40D and 300F units is shown in Fig. 10.

40D Frequency Control Unit. The 40D Frequency Control Unit employs a C-100D Oscillator controlled by means of a "HA" cut, low temperature coefficient crystal. The oscillator circuit makes use of the negative resistance principle and provides a very stable oscillator. The "HA" cut crystal has a temperature coefficient of less than three parts in a million per degree centigrade and thus if crystal heat should fail, the frequency could be maintained within the 50 cycle limit. The type 297 crystal oven has the temperature maintained by means of a mercury thermostat and is capable of maintaining the crystal temperature constant within a fraction of 1°C. Due to the construction of the 297 crystal oven, operating temperature is reached within 30 minutes after application of power so that power failure during night would not mean operation with a cold crystal as the crystal oven would heat in warming up period of the transmitter.

For insuring against loss of time on the air, positions are provided for two crystal ovens complete with crystal thermostat, thermometer, and associated relay with means for switching either into the oscillator circuit. In this way, one oven can be removed for replacement of crystal, thermostat, or relay without interrupting the use of the other crystal oven.

Following the oscillator, a type 45 tube is used as an untuned buffer loosely coupled to the oscillator to avoid frequency change due to changes in circuit or operating conditions of following stages.

An output of 10 to 15 watts is available from the RK23 pentode used as amplifier in the 40D Frequency Control Unit. This output is arranged to be link coupled to the following stage.

The 40D Frequency Control Unit has a self-contained power supply employing a 5Z3 in a single-phase full-wave rectifier.

Intermediate Radio Frequency Amplifier Stage. The intermediate radio frequency amplifier stage consists of a CK70 r-f pentode. The grid tank circuit is link coupled from the 40D Frequency Control Unit and is tuned by the knob located on the chassis of Unit D[1] designated INT. AMP. GRID TUNING. The plate tank circuit is tuned by the designated dial on the control panel. Bias is obtained by means of grid leak; suppressor voltage is obtained from the low voltage power supply; and both plate and screen voltages are supplied from the main power supply of the transmitter. It should be understood that the meter reading designated INT. AMP. PLATE CURRENT is the total cathode current and not the plate current flow alone.

Final Radio Frequency Amplifier Stage. The last radio frequency amplifier stage consists of 2 Collins C-201 tubes in parallel. These tubes are operated as class "C" amplifiers with plate modulation. Grid bias for this stage is obtained by means of a grid leak. Tuning of the plate circuit is made by the variable condenser operated by the designated dial on the control panel. Neutralization is obtained by inductive coupling of the grid inductance and the plate tank circuits. These controls are accessible from

[1] Unit D chassis is the top chassis in the 300F rack assembly.

the cabinet rear without opening the cabinet doors.

Antenna Circuit. The output circuit of the 300F Transmitter consists of a tank circuit with capacity coupling suitable for matching to a coaxial transmission line having a surge impedance on the order of 75 ohms. This tank circuit has the configuration of a low pass filter and is designed for a cut-off frequency very close to the fundamental, thus obtaining high attenuation to the transfer of power at high harmonic frequencies.

The transmission line may run directly to the tuning unit at the base of the antenna or to a separate unit for coupling to a balanced two-wire transmission line. Thus in the use of a balanced two-wire line, harmonic radiation from the line is eliminated because these harmonics are essentially eliminated in the coupling network to the high impedance line.

Audio Frequency Amplifier Stage. The first audio frequency amplifier stage consists of two 2A3 tubes operating in push pull class "A". These tubes obtain their bias by a cathode resistor, Item 129. The input to the transmitter is a 500 ohm-to-grid transformer. For 100% modulation, a pure tone of approximately plus 9 db at 500 ohm level is required using 6 mw. as zero level.

Class "B" Modulator Stage. The class "B" modulator stage consists of two type C838 zero bias tubes. These tubes are capable of 250 watts audio power output with a negligible amount of audio frequency distortion. The output of this stage is transformer coupled to the plate circuit of the final radio frequency amplifier stage.

Low Voltage Rectifier. The low voltage rectifier consists of a 5Z3 single phase full wave rectifier. The primary of the plate transformer is supplied from 110 volts AC and the low voltage plate supply comes on at the same time as the filament power to the 300F Amplifier. The voltage of approximately 400 volts is used for plate supply to the first audio frequency amplifier stage and for the positive suppressor voltage to the CK70.

Main Power Supply. The main power supply consists of two 872 mercury vapor rectifiers in a single phase full wave rectifier circuit. This power supply is also operated from 110 volts AC and supplies 1250 volts to the plate circuit to the intermediate radio frequency amplifier stage, final radio frequency amplifier stage, and class "C" modulator stage.

Power And Control Circuits. The 300F Transmitter may be operated either from 110 volts 50/60 cycle single phase or from 220 volts 3 wire 50/60 cycle single phase. The 40D Frequency Control Unit operates from 110 volts AC and the power circuits are controlled by switches on the panel. The filament and low voltage power supply circuits of the 300F Amplifier are energized by means of a relay operated from the control panel by a push button station. In the case of 220 volt 3 wire operation, this power is obtained from one side of the 220 volt service.

Operation of the filament push button energizes relay 169 and also applies power to time delay relay 170. This relay allows sufficient time for the filaments to warm before plate voltage may be applied. After the operation of relay 170, relay 171 may be operated by means of the push button station applying plate power to the transmitter.

Overload relay 172 has its coil located in the primary of the transformer for the main rectifier and in case of excessive current, this relay opens the holding circuit for relay 171. Door switches are also added in series with this holding coil, so that opening of any of the access doors also removes plate voltage from the transmitter. Furthermore, this holding circuit is completed through the fuse in the circuit of the filament transformer for the 872 rectifier tubes so that plate power will not be applied in case there is no filament voltage due to an open fuse.

Monitoring Equipment. Space is available in the 19" rack cabinet provided for the 40D Frequency Control Unit to mount a frequency monitor and frequency deviation meter. The connections are available on the output of the 40D Frequency Control Unit for applying a small radio frequency voltage to the frequency monitor.

A variable tap is provided on coil 180 for supplying a part of the radio frequency output of the transmitter to a modulation monitor. This should be link coupled to a tank circuit at the input of the modulation monitor which may be conveniently located in the speech rack or in the same rack as the frequency monitor. Audio monitoring can be obtained either by amplifying the audio voltage available from the modulation monitor or by use of a second diode rectifier across the radio frequency input to the monitor.

Power Reduction. Unless ordered for operation at a single power, the 300F Transmitter is arranged for reducing power from 250 watts to 100 watts for night operation. This is accomplished by a reduction in excitation, a reduction in plate voltage and a reduction in audio input. Relay 179 when operated causes resistance 128 to be added in the plate circuit to the final radio frequency amplifier. This resistance is adjustable for adjusting the power reduction to the proper value. Also resistance 127 is added into the plate circuit of the CK70. This reduces excitation to the final amplifier and maintains a linear modulation characteristic. The audio frequency input must be reduced 3 db by manual control.

(B) INSTALLATION.

300F Amplifier and Modulator. The 300F Amplifier and Modulator requires either 220 volt 3 wire or 110 volt 2 wire 50/60 cycle single phase. Power leads should be installed capable of supplying a 2 kva load. The maximum power requirements of the transmitter is approximately 1500 watts under 100% modulation. The 300F Amplifier has removable dust covers on either side, allowing access to all cabling. Power conduit is to be terminated in the channel at the rear right-hand side of the cabinet and leads brought direct to terminals 7B, 8B, and 9B[1] through the grommet hole designated POWER LEADS. In case of 110 volt 2 wire operation, terminals 7B and 9B are connected together and are one side of the AC line.

[1] In Fig. 10, 7B is labeled "plate pwr.", 8B is "common", and 9B is "Filament power", 13D and 14D are "audio 500 Ω" and 9D and 10D are "400 exciter" and ground.

In addition to the power circuit there is required the audio input and the r-f input to the 300F Amplifier and Modulator. These also enter on the rear right-hand side of the transmitter, through the designated grommet hole and terminate at 13D and 14D; and 9D and 10D respectively. Both the r-f output to the transmission line and to the modulation monitor are at the top right-hand side of the transmitter in the front channel. The radio frequency transmission line may be taken out either at the bottom or the top of the channel at this side. Shielded microphone cable may be used as a concentric transmission line for the two link circuits between the 40D Frequency Control Unit and the transmitter and between the transmitter and the modulation monitor.

Frequency Control Unit. The 110 volt 50/60 cycle provided for the 40D Frequency Control Unit should preferably be through a separate distribution switch than that of the 300F Amplifier. In this way all voltage may be removed from the amplifier without removing heat from the crystal ovens in the frequency control unit. The power requirement of the 40D Frequency Control Unit is approximately 150 watts.

In addition to the power circuit for the 40D Frequency Control Unit, Frequency Monitor and any other equipment mounted in this rack, there is also the excitation lead to the 300F Amplifier and Modulator. In case the line amplifier is located in this cabinet along with the modulation monitor, additional audio leads from the incoming line and to the transmitter, as well as the r-f link for the modulation monitor must be provided.

If the transmitter is to be located at a point remote from the studio, a suitable line amplifier must be used to amplify the telephone line signal to the level required by the transmitter. While this line speech amplifier may be installed in the frequency control unit cabinet together with various monitors, this position is not the best and it is recommended that a separate cabinet be used to carry the line amplifier, monitoring amplifier, modulation monitor, and any other audio equipment located at the transmitter.

(C) ADJUSTMENT OF APPARATUS.

Preliminary Test of Power and Control Circuits. With all tubes removed and the power leads connected to the transmitter, the relay circuits of the transmitter may be tested. Special relay oil furnished should be added to dash pot of time delay relay 170 according to instructions on the side of the dash pot. Relay 172 must be left without oil to give instantaneous operation under overload. Operation of the filament push button station should cause relay 169 to operate as well as lighting of pilot light and meter lights, and after a short time, interval relay 170 should operate. The delay interval of the 170 relay may be adjusted as indicated on the side of the relay. If the door switches are all operated, operation of the plate power push button station should cause relay 171 to operate. The filament voltages should be observed and if these are not more than 15% high, it is safe to put the tubes in the sockets.

Frequency Control Unit. Crystal holders, thermometers and tubes should be inserted in the 40D Frequency Control Unit. Switch on rear of chassis applies power to crystal oven heaters and heat indicators should light. About 30 minutes is required for these ovens to reach operating temperature of 50°C, at which point the heat should be on and off about equal intervals of 20 to 40 seconds.

Operation of filament switch also applies plate voltage to oscillator and 45 buffer. Rotation of oscillator tuning control should show oscillation as indicated by grid current to the amplifier. The oscillator tuning control is an adjustment of plate voltage and should be set for maximum grid current to the amplifier.

Operation of plate switch applies power to the amplifier plates and the tuning condenser should be adjusted to minimum plate current and grid current should be 3 to 4 milliamperes.

If frequency does not agree with monitor, a few cycles change may be obtained by adjusting oscillator tuning. If this requires much adjustment, the airgap should be adjusted on the crystal holder in order that maximum frequency stability be maintained. The name plate on the crystal holder may be removed giving access to the airgap adjustment. Care should be taken to loosen lock nut and not to change airgap more than a few degrees of rotation. Rotating the center piece in a clockwise direction, closing airgap, lowers the frequency while counter-clockwise motion increases the frequency.

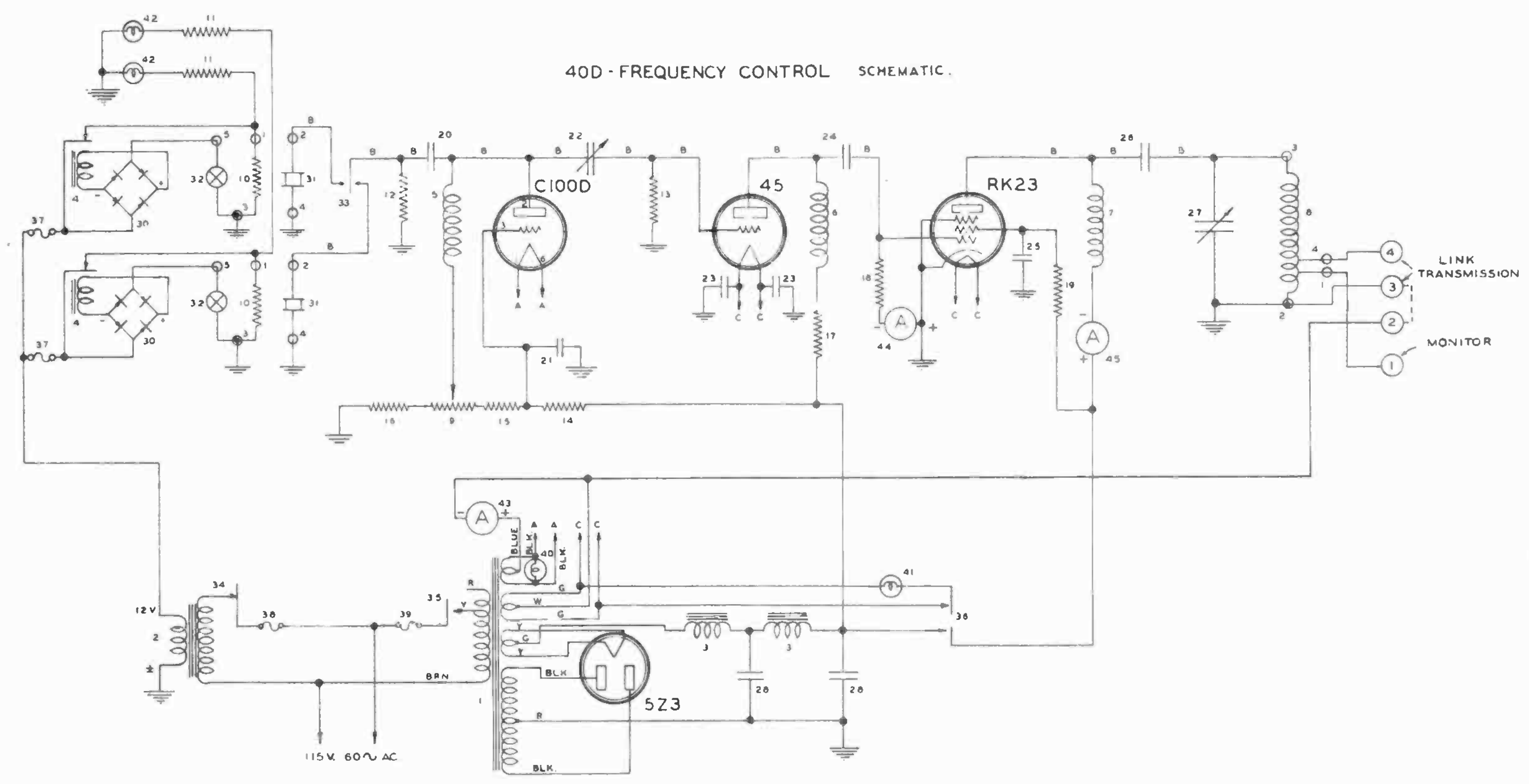
Filaments. After all tubes have been inserted in the 300F Amplifier and Modulator, apply filament power by operating the filament power push button. With voltmeter key switch in position for CK70 filament, adjust filament voltage rheostat on control panel for 7.5 volts. Then switch key switch to final amplifier filament voltage. This should read 10 volts and if not it should be adjusted by means of rheostat, Item 130. The tubes must be operated at full rated filament voltage for a period of 15 minutes before plate voltage is applied.

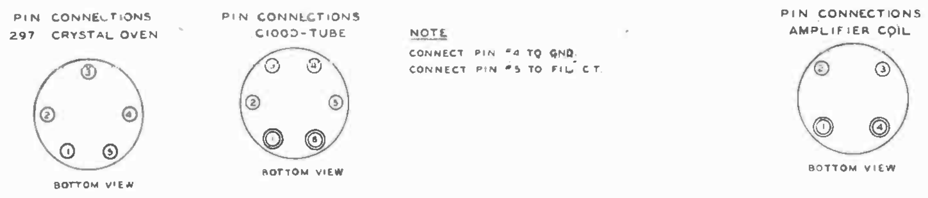
Application of filament power applies plate power to the speech amplifier, the plate current of which may be read on the designated meter.

Intermediate Radio Frequency Amplifier Stage. By adjusting the tap on coil 113, the grid current of the intermediate radio frequency amplifier stage should be adjusted for 3 to 4 ma. with the grid condenser, Item 138, tuned for maximum grid current. The tuning of the 40D amplifier should also be checked to see that minimum plate current is maintained.

By opening the FINAL AMP. PLATE PWR. SWITCH, Item 185, the plate voltage may be applied only to the CK70 and the 838 modulators. With this connection removed, plate power should be applied and an immediate tuning of the intermediate radio frequency amplifier plate condenser should be made for minimum plate current. With application of plate power the modulator plate current should also be checked, its normal value being approximately 160 ma. with zero signal.

Final Radio Frequency Amplifier Stage. With the excitation to the final radio frequency amplifier, the plate tuning condenser should be rotated to a point where the tank circuit tunes as in-





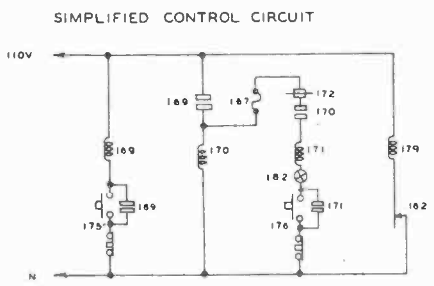
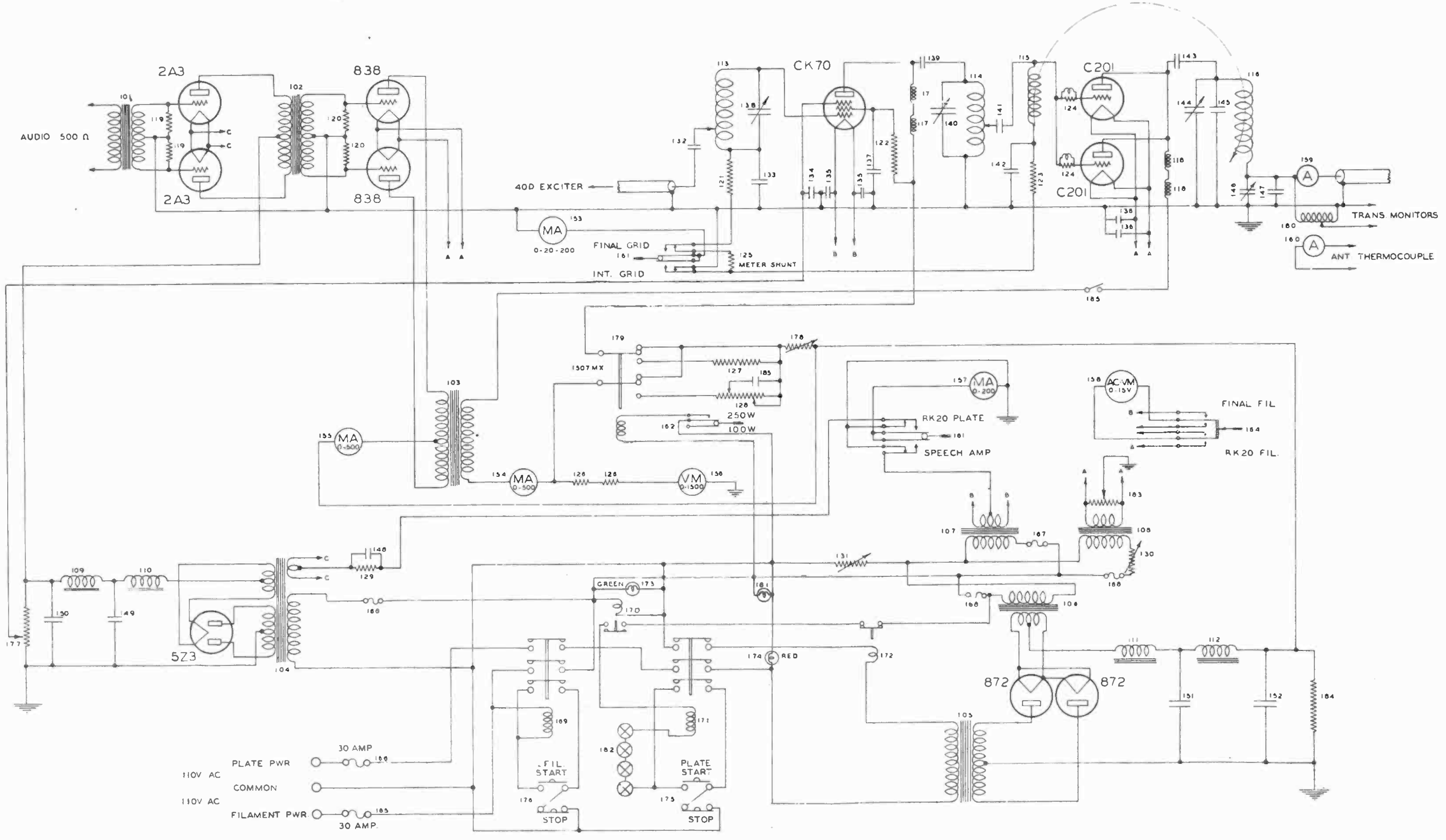


Fig. 10 Schematic drawings showing the Collins 40D Frequency Control Unit and 300F Broadcast Transmitter, respectively.



dicated by a dip in grid current or by reading on a thermogalvanometer loosely coupled to the plate circuit. Neutralization should be adjusted for minimum reading on the thermogalvanometer or minimum change in grid current, by rotating neutralizing coil 115. This may be operated by a screw driver, the adjusting drive being on the rear ventilator panel on the right side of the transmitter.

After neutralization has been completed, the FINAL AMP. PLATE PWR. SWITCH may be closed after which plate power may be again applied and exact tuning of the plate circuit obtained by minimum plate current. With the dummy resistance or the transmitter connected to the transmission line, the loading should be adjusted by condenser, Item 146. The adjustment is made with a screw driver and the drive located in the ventilator panel on the back and at the left-hand side of the cabinet. Increasing capacity of this condenser decreases the input to the final amplifier.

Plate voltage may be adjusted by means of the potentiometer mounted on the control panel. This gives a range of approximately plus or minus 5% in plate voltage for maintaining proper input to the transmitter due to line voltage variation. The primary of the main power supply transformer is also tapped so that approximately correct voltage can be obtained by adjusting the tap.

The grid current to the final amplifier with plate voltage applied should be approximately 100 ma. This can be adjusted by means of the tap on coil 114.

CAUTION: Extreme care should be used at all times if door switches are shorted out.

Power Reduction. Key switch 162 on the control panel when operated to the 100 watt position operates relay 179, reducing plate voltage on both the intermediate and final amplifier stages. Since the modulation characteristics of the final amplifier are approximately linear, the power input will vary as the square of the plate voltage so that to reduce power from 250 watts to 100 watts, the plate power must be reduced from 333 ma. at 1250 volts to 210 ma. at 790 volts. The amount by which plate voltage is reduced can be adjusted by means of the adjustable tap on resistance 128.

(D) MAINTENANCE.

General. For best operation, the 300F Transmitter must be kept free from dust and dirt. High pressure air and suction vacuum cleaner with hose adjustment is recommended for this purpose.

All nuts, bolts and screws should be examined occasionally and loose ones tightened. All electrical connections should be examined and tightened if loose contacts are found. Loss of time on the air can be avoided by these precautions.

Regular checks of transmitter performance should be made with transmission measuring equipment if such is available. In addition to disclosing maladjustment of any of the transmitter circuits, this procedure will usually show up poor tubes before they must actually be replaced to avoid a shutdown.

Filament voltages should be checked at regular intervals and maintained at their proper value. If filaments are operated at low voltage, the life is shortened due to loss of emission; on the other hand, excessive voltage will result in a shorter life due to local heating of the filament causing the filament to burn out.

Relays. All relays should be examined at regular intervals to see that the contacts are clean and to replace burned contacts. Abrasives such as fine files or emery cloth should never be used on relay contacts. In the case of badly pitted contacts, replacement of the contacts should be made.

Time delay relay 170 should have oil in the dash pot. The amount of time delay obtained may be adjusted either by adjustment of the plunger or by adjustment of the by-pass valve on the plunger. Overload relay 172 should only have a few drops of oil in the dash pot. This is sufficient to avoid operation of the relay due to the inductive surge of the transformer when plate power is first applied, but allows the relay to operate rapidly in case of an overload.

Operation of Transmitter. It is recommended that the power circuit to the crystal ovens be left energized at all times so that the crystal temperatures may be constant. However, in case of power failure during night, the crystal ovens will reach operating temperature in approximately 30 minutes.

First, the 40D Frequency Control Unit should be adjusted by applying power to filament and plate circuit and checking the meter readings and frequency deviation. Then the filaments of the transmitter should be energized and allowed to warm for a few minutes be fore application of plate power. Not more than 10 minutes should be required in placing the transmitter on the air of a morning. Every time the transmitter is placed in operation, filament voltages and plate input to the final amplifier should be checked.

(E) PERFORMANCE.

TYPICAL METER READINGS

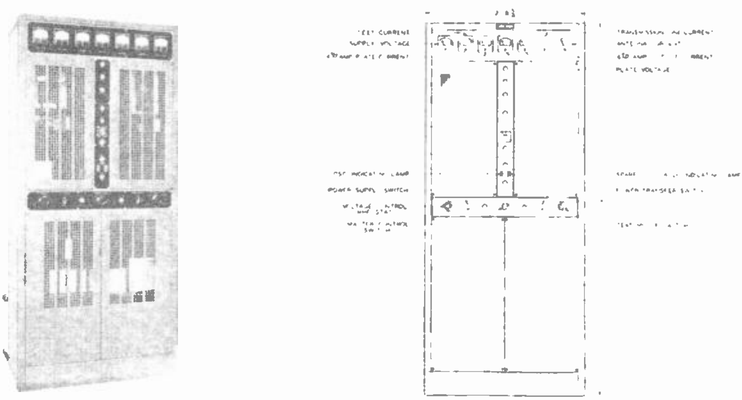
	250 Watt
Final Amp. Plate Voltage	1250 Volts
Final Amp. Plate Current	333 Ma.
R.F. Line Current No Modulation	1.95 Amp.
Antenna Current	Dependent upon antenna characteristic.
Final Amp. Grid Current	100 Ma.
Intermediate Amp. Plate Current	70 Ma.
Intermediate Amp. Grid Current	8 Ma.
Speech Amp. Plate Current (no signal)	80 Ma.
Int. Amp. Filament Voltage	7½ V a.c.
Final Amp. & Modulator Filament Voltage	10 V a.c.

	100 Watt
Final Amp. Plate Voltage	790 Volts
Final Amp. Plate Current	210 Ma.
R.F. Line Current No Modulation	1.3 Amp.
Antenna Current	Dependent upon antenna characteristic.
Final Amp. Grid Current	100 Ma.
Intermediate Amp. Plate Current	60 Ma.
Intermediate Amp. Grid Current	8 Ma.
Speech Amp. Plate Current (no signal)	80 Ma.
Int. Amp. Filament Voltage	7½ V a.c.
Final Amp. & Modulator Filament Voltage	10 V a.c.

WESTERN ELECTRIC 23A RADIO TRANSMITTER

(A) GENERAL DESCRIPTION.

The Western Electric No. 23A Radio Transmitter will deliver a maximum of 250 watts of completely modulated radio frequency carrier power at any frequency between 550 and 1600 kc. Normally it operates from a 200-240 volt single-phase, 50-60 cycle, power source, requiring approximately 2300 watts at a 90% power factor for 250-watt operation and approximately 1900 watts at a 90%, power factor for 100 watt operation. An auto-transformer, which must be ordered separately, can be supplied for 100-120 volt, single-phase, 50-60 cycle operation where 200-240 volt power is not available. A photograph of the front of the transmitter and an outline dimensional diagram are shown in Fig. 11.



(A) (B)

Fig.11 (A) Photograph showing front view of the Western Electric 23A Broadcast Transmitter. (B) Outline dimensional diagram of same transmitter.

The No. 310A and No. 310B Radio Transmitting equipments each consist of a fully equipped No. 23A Radio Transmitter and differ only in the number of vacuum tubes used in the final radio frequency amplifier. The No. 310A Radio Transmitting Equipment uses four vacuum tubes for 100-watt service and the No. 310B Radio Transmitting Equipment uses six vacuum tubes in the final amplifier for 100/250 watt service.

The No. 23A Radio Transmitter consists of a quartz-controlled oscillator, a buffer amplifier, a balanced modulating amplifier followed by two radio-frequency balanced linear amplifier, two stages of audio-frequency amplification, a feedback rectifier and a plate voltage rectifier with associated filter and control circuits. A flashing signal lamp indicates proper operation of the oscillator temperature control circuit.

Modulation in the No. 23A Radio Transmitter is effected in the multi-element tubes of the second amplifier. The radio frequency voltage is applied to the control grids, and the audio frequency voltages are applied to the suppressor grids. This is essentially suppressor grid modulation in that the bias on the suppressor grids is varied in accordance with the audio frequency voltage applied to them. A complete schematic diagram of the 23A is shown in Fig. 12.

Stabilized feedback is used in the transmitter to reduce the noise and the audio frequency harmonic distortion normally present in the output wave of radio transmitters.[1]

(B) INSTALLATION.

When the No. 23A Radio Transmitter has been installed and connected in accordance with the installation information furnished with the equipment, the procedure indicated below should be followed.

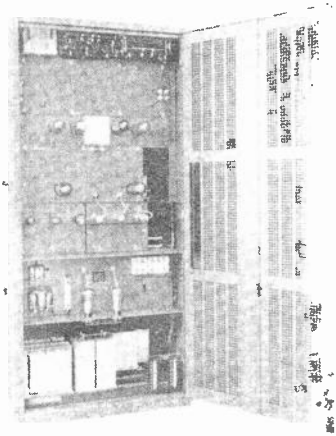


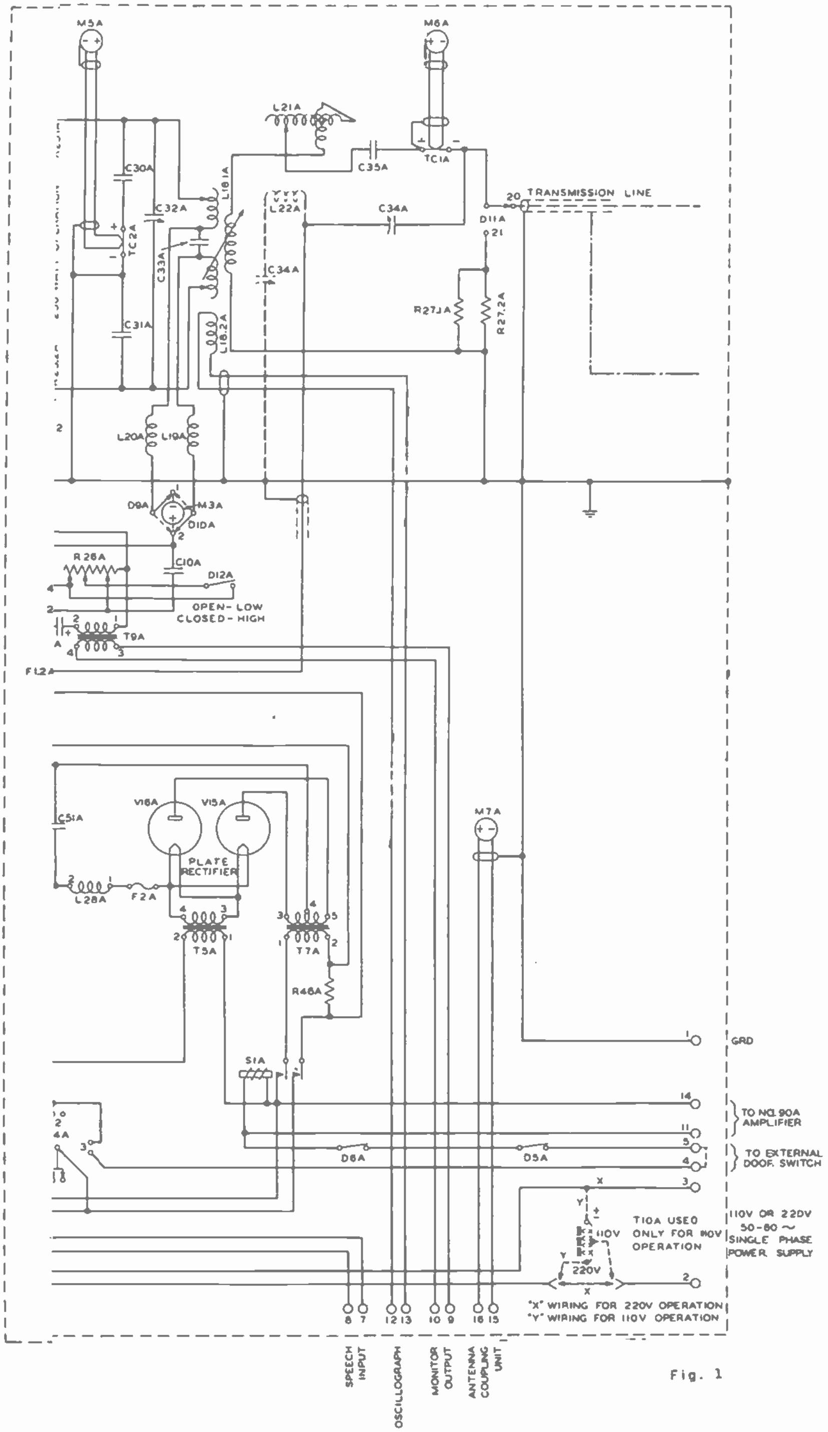
Fig.13 Photograph showing rear view of Western Electric 23A Broadcast Transmitter.

Vacuum Tubes and Fuses. Place two No. 249B Vacuum Tubes in the sockets, VS15A and VS16A. Place the clip leads on the anodes of the tubes. Insert from left to right (see Fig. 13) a No. 244A, a No. 262A, a No. 271A, and three RCA 837 Vacuum Tubes, designated V12A, V13A, V14A, V3A, V2A, and V1A, respectively in the sockets of the audio and frequency amplifiers. Connect the clip leads to vacuum tubes V1A, V2A, V3A and V13A.

Place six (or eight) No. 242C Vacuum Tubes, as required, in the sockets VS4A to VS9A or VS11A, inclusive. Place a two-watt, 18-volt, G.E.Co. type 4 Lamp in each of the candelabra sockets, ES1A and ES2A.

Insert two 5-ampere, 250-volt Cartridge Fuses in cut-outs FM1.1A and FM1.2A, two 2-ampere, 250-volt Cartridge Fuses in cut-outs FM3.2A and FM3.3A and a 2-ampere, 2500-volt Western Union Telegraph Fuse in cut-out FM2A, Do not install a fuse in cut-out FM3.1A.

[1] Stabilized feedback circuits are fully discussed in Lesson 9, Unit 4.



M5A
M6A
L21A
C35A
TC1A
C30A
C32A
L18.1A
L22A
C34A
TRANSMISSION LINE
D11A
TC2A
C33A
R27.1A
R27.2A
C31A
L18.2A
L20A
L19A
D9A
M3A
D10A
R26A
C10A
D12A
OPEN- LOW
CLOSED- HIGH
T9A
F1.2A
V16A
V15A
C51A
PLATE RECTIFIER
L28A
F2A
T5A
T7A
R46A
M7A
S1A
GRD
TO NO. 90A AMPLIFIER
D6A
D5A
TO EXTERNAL DOOR SWITCH
T10A USED ONLY FOR 110V OPERATION
110V
220V
110V OR 220V 50-60 ~ SINGLE PHASE POWER SUPPLY
"X" WIRING FOR 220V OPERATION
"Y" WIRING FOR 110V OPERATION
SPEECH INPUT
OSCILLOGRAPH
MONITOR OUTPUT
ANTENNA COUPLING UNIT

Fig. 1

No. 702A Oscillator. The No. 702A Oscillators, the No. 7A Quartz Plates and the Thermometers are shipped separately and should be assembled as specified in the Instruction Bulletin accompanying the Oscillator. Place a No. 247A Vacuum Tube in the oscillator tube socket, V1, and then replace the tube shield. Slide and lock the No. 702A Oscillator in place on the lower set of guide rails. If a spare No. 702A Oscillator is installed, slide and lock it in place on the guide rails provided above the regular oscillator.

(C) ADJUSTMENT AND TUNING PROCEDURE. The No. 23A Radio Transmitter may be adjusted and tuned in accordance with the following procedure:

CAUTION: DUE TO THE HIGH VOLTAGES EMPLOYED IN THIS TRANSMITTER, ALL FRONT AND SIDE PANELS SHOULD BE IN PLACE AND THE REAR DOOR CLOSED BEFORE ANY ATTEMPT IS MADE TO OPERATE THE EQUIPMENT.

With all switches in the "Off" position, connect power to the transmitter. Set the "Voltage Control" to the extreme counter-clockwise position and close the "Power Supply" switch (D3A) located in the rear of the transmitter. With the voltage control transformer, T3A, connected 1-4, as wired in the factory, the "Supply Voltage" (M1A) should read between 200 and 212 volts. If the reading is higher, move the connections on T3A to 1-5 and if it is too low, move the connections to 1-3. Open "Power Supply" switch. Close the "Oscillator Heater Supply" switch, (D1A), located in the rear and to the left and above the "Power Supply" switch. This permits the heating of the No. 702A Oscillator while the remainder of the adjustments are being made. The oscillator-heater indicator lamp E1A (and E2A if a spare oscillator is used) will remain lighted only until the associated oscillator is at the proper temperature, at which time the corresponding lamp will flash intermittently. The exact time of the "On" and "Off" intervals is dependent upon the ambient temperature.

Adjust the taps on inductance coils L3A, L8A, L11A, L18.1A and L21A and set controls of condensers C11A, C12A, C20A and C21A in accordance with Table I. (Page 35)

Connect link switch D11A to terminal No. 21. Place "Power Transfer" switch (D21A) in the "High" position. Place link switches D9A and D10A in position No. 1, and close link switch, D8A.

Preliminary Tuning. Close "Power Supply" switch and close the rear door. Operate "Master Control" switch (D4A) clockwise to the "Fil." position. Adjust "Voltage Control" until "Supply Voltages" indicates 200 volts.

After approximately 30 seconds turn "Master Control" switch clockwise to the vertical position and then to the "Plate" position.[1] Then close "High Voltage" switch (D5A) and observe the indication on "Plate Voltage" meter (M4A) which should be approximately 1300 volts. If this voltage is low, (approximately 750 volts) check op-

[1] It is essential that the filaments of new mercury vapor tubes be heated at least 15 minutes before the high voltage is applied.

eration of relay S2A in accordance with the information given under "Location of Trouble". In the following tuning procedure, the controls are adjusted with a spanner wrench furnished with the equipment. Place "Test Meter Switch" (D7A) in each of the eight positions, and note that in no case is the "Test Meter" (M2A) off scale.

Set "Test Meter Switch" in position "1st R.F. Amp. Plate" and adjust "1st Amp. Tuning" control (C4A and C5A) until "Test Current" meter reads a minimum. Change "Test Meter Switch" to "2nd R.F. Amp. Grid" and readjust "1st Amp. Tuning" slightly for a maximum on "Test Current" meter.

Adjust "1st Amp. Output" control (R8A) until "Test Current" meter reads approximately midway between the limits given in Table II (Page 35). Set "Test Meter Switch" to "2nd R.F. Amp. Plate" and adjust "2nd Amp. Tuning" control (C13A) until "Test Current" meter reads a minimum. Change "Test Meter Switch" to "3rd R.F. Amp. Plate" and adjust "3rd Amp. Tuning" control (C24A) until "4th Amp. Plate Current" reads a maximum. Check "2nd R.F. Grid" and "3rd R.F. Amp. Plate" currents with Table II.

Set "4th Amp. Coupling" control at zero and "4th Amp. Input" control (R20A) to approximately mid-position. Adjust "4th Amp. Tuning" control (C32A) until "4th Amp. Output Current" meter (M5A) reads a maximum. This is obtained alternately adjusting "4th Amp. Input" control and "4th Amp. Tuning" control until "4th Amp. Output Current" reads a maximum at approximately 1.0 ampere. The "Transmission line Current" meter (M6A) should read zero.

(D) NEUTRALIZING.

The third and fourth amplifiers must now be neutralized in the following manner: Shut down the transmitter and disconnect the thermocouple end of the lead between C34A and TC1A. With a temporary jumper, connect the free end of this lead to the clip on L21A. Set the test meter switch to the "Feedback Rec" position. Open link Switch D9A and D10A. Start the transmitter and increase the "4th Amp. Coupling" a slight amount. Adjust the "Coupling Circuit Tuning" control (L21A) for a maximum indication of the "Test Meter". Full scale reading of the "Test Meter" should not be exceeded during this process, a reduction in the setting of "4th Amp. Input" control being made if necessary to reduce the "Test Meter" reading to somewhat less than full scale. If insufficient reading of the "Test Meter" is obtained to give a good indication, the capacity of C34A should be increased until a satisfactory value is obtained. Neutralize the fourth amplifier by adjusting the "4th Amp. Neutralizing" (C27A) and (C27A) control for a minimum indication of the "Test Meter". Shut down the transmitter, open link switch D8A and close link switches D9A and D10A to position 1 as before. Start the transmitter and neutralize the third amplifier by adjusting the "3rd Amp. Neutralizing" control (C18A) and (C19A) for a minimum indication of the "Test Meter". Shut down the transmitter, close link switch D8A, remove the temporary jumper, recconnect C34A to TC1A, set the "4th Amp. Output Coupling" and C34A to zero.

For transmitters prior to serial #126, a modification of the connection changes to be made preparatory to neutralizing is necessary. In these transmitters, the condenser C34A is connected to coil L22A, instead of to TC1A. Therefore, in this case, the lead connecting L22A to C34A should be removed from C34A and connected by means of a temporary jumper to the point between C35A and C36A. With this change in connections, the neutralizing procedure should be carried out exactly as previously described.

(E) OUTPUT TUNING.

Increase "4th Amp. Coupling" a slight amount and then tune the coupling circuit by adjusting "Coupling Circuit Tuning" control until the "4th Amp. Output Current" meter indicates a minimum. Then check the tuning of the 4th amplifier for minimum plate current.

Adjust alternately the "4th Amp. Input" control and the "4th Amp. Coupling" until the "4th Amp. Plate Current" is in accord with Table II when the "Plate Voltage" is 1250 volts, the "Supply Voltage" is 200 volts, the "4th Amp. Output Current" is approximately 0.5 ampere, and the "Transmission Line Current" meter (M6A) indicates the proper output for the power of the transmitter as shown in Table II.

The "4th Amp. Plate Current" meter, is normally connected to indicate the total plate current in the vacuum tubes of the final amplifier. The plate current indication on this meter of tubes V6A and V8A or V6A, V8A and V10A when D9A is in position 1 and D10A is in position 2 should be within 10 ma. of the plate current indication of tubes V7A and V9A or V7A, V9A and V11A when D9A is in position 2 and D10A is in position 1. This balance can be obtained by adjusting the relative positions of the contact arms on resistors R20.1A and R20.2A. The amount that either of these controls should be moved depends upon the unbalance indicated on "4th Amp. Plate Current" meter.

When all tuning adjustments are completed, and the transmitter delivering the desired output power, the meter readings shall be in accordance with Table II, "Typical Meter Reading", with the exception of the "Feedback Rec." current which will be adjusted later.

The transmitter is now ready to be connected to the concentric transmission line by connecting link switch D11A to terminal 20. This line connects the output of the transmitter to the Antenna Coupling Unit which is adjusted and tuned in accordance with Instruction Bulletin accompanying it.

Set the feedback rectifier input control until the "Feedback Rec." current is as indicated in Table II. If an audio oscillator is available, a more accurate setting of feedback may be made as follows: With the single frequency audio input level to the transmitter adjusted to the value of Table II, the output for complete modulation should be observed as an increase of 22½% on the "Transmission Line" meter. If the current increase is either more or less than this increase or decrease, respectively, C34A until the proper percentage is attained. This will provide the proper amount of stabilized feedback. The "Feedback Rec." current indicated on the "Test Current" meter should be within the limits given in Table II.

(F) OPERATING PROCEDURE.

When the No. 23A Radio Transmitter is adjusted and tuned as described in the preceding paragraphs, the routine operation is as follows:

The "Oscillator Heater Supply" switch (D1A) is always left "On" in order to furnish power to the oscillator heater circuits.

Before starting the transmitter, the antenna-ground switch shall be connected to the antenna position, the link switch D11A in the transmitter shall be connected to terminal No. 20, and the "Power Transfer" switch shall be either in the "High" position for 250-watt operation or in the "Low" position for 100-watt operation. The position of "Power Transfer" switch for 100-watt operation refers to either the No. 310A or No. 310B Radio Transmitting Equipment.

> *NOTE:* Never operate the 310A Radio Transmitting Equipment with the "Power Transfer" switch in the "High" position.

The "Power Supply Switch" is closed, followed by the operation of the "Master Control Switch" to the "Fil." position and after a pause of at least 30 seconds to the "Plate" position. If the "High Voltage" switch is "On" the transmitter will deliver power to the antenna. If the "High Voltage" switch is "Off", it may be operated at the convenience of the operator at any time after the "Master Control Switch" has been operated to the "Plate" position. The output power may be slightly high at first, but will be normal as soon as the equipment has attained the operating temperature.

> *CAUTION:* In the event of power failure, the "High Voltage" switch should be operated immediately to the "Off" position. The plate voltage may be applied after a 15 second delay following the return of the power as indicated by the "Supply Voltage" meter.

The transmitter is shut down by operating the "Master Control" switch clockwise to the "Off" position. The transmitter may be shut down for a short interval by the "High Voltage" switch. For long shut down periods, operate the "Power Supply" switch to "Off" in addition to the "Master Control" switch.

Modulation and Monitoring. The single frequency level of audio power required to completely modulate the transmitter is given in Table II. For fine quality, the program level for complete modulation should be 6 db lower than the single frequency level. Visual monitoring of the carrier may be accomplished by connecting a chathod ray oscilloscope to terminals Nos. 12 and 13. A simple anti-resonant circuit across the input of the oscilloscope may be used to increase the deflection.

Monitoring of the transmitter is accomplished by connecting transmitter terminals Nos. 9 and 10 to the monitoring equipment. The impedance of this monitoring circuit is 500 ohms and it should be so terminated.

Reduced Power Operation for the No. 310B Equipment. In order to reduce the power output from 250 watts to 100 watts, the

"Power Transfer" switch is operated to the "Low" position. The "4th Amp. Coupling" and "4th Amp. Input" controls are adjusted until the proper plate current and transmission line currents are obtained as given in Table II. The audio input level is reduced 5 db below the level required for 250 watt operation as indicated in Table II.

(G) MAINTENANCE.

General. Cleanliness is essential to the best operation of this equipment and the unit must be kept free from dust and dirt. Compressed air or equivalent is recommended for cleaning the apparatus inside the enclosure, but a soft clean cloth may be used with good results. Waste or oily cloth should never be used.

Care of Cabinet. The lacquered surfaces and chromium trim may be polished by rubbing them with a piece of soft cloth moistened with metal polish and finally wiping with a dry, clean soft cloth. Any visible grease, oil or wax should first be removed with carbon tetrachloride before applying the polish.

Air and Electrolytic Condensers. The variable air condensers in the shielded compartments should be cleaned at least once a month with compressed air or equivalent. This prevents the collection of dust which may result in the arcing of the condensers, thereby taking the station "off the air". C32A shall not be opened as it is sealed against dust.

The electrolytic condenser (C29A), associated with the monitoring circuit, has a life of approximately one and one-half years and should be replaced about once a year. In replacing this condenser, it is essential that the correct polarity be maintained.

Voltage Control Transformer (T3A). The sliding surface of the voltage control transformer (T3A) should be cleaned at weekly intervals with a lintless cloth slightly moistened with carbon tetrachloride. In general, T3A should be given the same care as that required by the commutator and brushes of a motor.

Vacuum Tubes. In order to obtain both maximum life and satisfactory performance, it is important that vacuum tubes be operated within their voltage limits. (See Table II). As far as possible the operator should anticipate tube failures and make the required tube replacements. Tube failures may be guarded against to some extent by keeping a careful record of the length of time the tubes have been in service and by observing from time to time the condition of the tube elements.

When the glow of the mercury vapor rectifier tubes V15A and V16A changes from the normal bluish-green to a very pale blue, the tubes have reached the end of their useful life and should be replaced.

It is essential that the filaments of new mercury vapor tubes be heated at least 15 minutes before the high voltage is applied. This is in order to remove any particles of mercury adhering to the sides or elements of the tubes which might result in flashovers. Spare rectifier tubes should be prepared for service in advance by placing them in the equipment when not in use and giving the filaments the necessary preheating with the "High Voltage" switch (D5A) in the "Off" position. This procedure should be repeated at least once a month. Spare rectifier tubes thus preheated should be kept in an upright position until they are required.

Thermocouples. Whenever damaged external heating elements associated with the radio frequency meters are sent in for repairs, the heating elements must be accompanied by the associated meter for calibration purposes.

Additional Routine. Once a month test all nuts, bolts and screws and tighten any loose ones. Also, check all connections and if any loose contacts are found they should be made secure. Cases of trouble can often be prevented by such precaution.

(B) LOCATION OF TROUBLE.

General. If this equipment is regularly and carefully maintained, very little trouble will be experienced. A new operator should endeavor to become familiar with the circuits, their functions and the location of apparatus as quickly as possible.

In case of trouble in any of the control or protection circuits, the operator should remember that these circuits are interlocked so that the failure of one piece of apparatus often prevents other pieces from functioning. For example, should the plate voltage relay (S1A) fail to operate, the "High Voltage" switch (D5A), door switch (D6A), and the door switch in the Antenna Coupling Unit should be investigated. Any one of these may be causing the trouble. This method of checking through circuits should be continued until the defective piece of apparatus is located.

Trouble in the radio frequency circuits is usually caused by improper adjustment. The first step in case of trouble in these circuits should be to see that all adjustments are in accordance with those described in this material, as well as with the adjustments recorded in the station log.

Surge Suppression Relay. Should relay S2A fail to operate as indicated by low (Approximately 750 volts) "Plate Voltage" on meter M4A, adjust the slider tap on R49.1A until the voltage between this tap and ground measures approximately 100 volts when the transmitter is delivering its rated output power. Under this condition, relay S2A should operate a fraction of a second after "High Voltage" switch (D5A) is operated.

TABLE I

Western Electric No. 23A Radio Transmitter
APPROXIMATE RADIO FREQUENCY ADJUSTMENTS
To Accompany Temporary Instruction Bulletin

550 to 1600 KC

f KC	L3A Total Turns	L18.1A Total Turns	L21A Total Turns (1)	L21A Total Turns (2)	C11A C12A Div.	C20A 012A	C30A C31A Mfd.	C35A C36A Mfd.
550	130	38	70	40	50	65	.0004	.0006
600	120	34	63	34	50	65	.0004	.0006
690	110	30	58	29	50	65	.0004	.0006
700	108	30	54	30	45	60	.0004	.0005
750	104	28	51	26	45	60	.0004	.0005
770	102	26	50	24	45	60	.0004	.0005
780	102	26	49	22	45	60	.0004	.0005
840	98	24	47	20	45	60	.0004	.0005
850	96	24	44	25	40	60	.0004	.0004
900	92	22	42	23	40	60	.0004	.0004
910	92	24	41	22	40	50	.0002	.0004
950	86	24	38	19	40	50	.0002	.0004
990	82	24	35	16	40	50	.0002	.0004
1000	80	24	33	15	40	50	.0002	.0004
1090	74	22	30	13	40	50	.0002	.0004
1100	72	22	27	19	35	40	.0002	.0003
1150	68	22	25	17	35	40	.0002	.0003
1200	64	22	23	15	35	40	.0002	.0003
1250	60	20	21	13	35	40	.0002	.0003
1300	58	18	20	10	35	40	.0002	.0003
1310	58	18	24	10	35	40	.0002	.0003
1350	54	18	23	9	30	30	.0002	.0003
1400	50	18	22	7	30	30	.0002	.0003
1450	46	18	20	6	30	30	.0002	.0003
1500	44	16	18	5	30	30	.0002	.0003
1510	44	16	17	13	30	30	.0002	.0002
1600	38	16	15	10	30	30	.0002	.0002

TABLE II

TYPICAL METER READINGS

Circuit Designations	Meter Scale	No. 310A	No. 310B
Power Supply Voltage (M1A)		220 volts	220 volts
Osc. Plate Current (M2A)	0-5 ma.	2-4 ma.	2-4 ma.
1st R.F. Amp. Plate Current (M2A)	0-50 ma.	7-13 ma.	7-13 ma.
2nd R.F. Amp. Grid Current (M2A)	0-2 ma.	.4-1.5 ma.	.4-1.5 ma-
2nd R.F. Amp. Plate Current (M2A)	0-300 ma.	30-60 ma.	30-60 ma.
3rd Amp. Plate Current (M2A)	0-300 ma.	135-175 ma.	135-175 ma.
4th Amp. Plate Current (M3A)	-	237-243 ma.	580-620 ma. 237-243 ma. for 100 watts
Plate Voltage (M4A)	-	1250 ±25 V.	1250 ±25 V.
4th Amp. Output Current (M5A)	-	0.4-1.1 amp.	0.4-1.1 amp.
Transmission line Current (M6A)	-	1.21-1.27 amp.	1.9-2.1 amp. 1.21-1.27 amp. for 100 watts
Feedback Rect. Current (M2A)	0-1 ma.	0.2-0.4 ma.	0.4-0.6 ma.
1st A.F. Amp. Plate Current (M2A)	0-5 ma.	2-4 ma.	2-4 ma.
2nd A.F. Amp. Plate Current (M2A)	0-50 ma.	35-50 ma.	35-50 ma.

SPEECH INPUT LEVELS.

The following speech input power levels at terminals 7 and 8 are required for complete modulation of the carrier.

	No. 310 - 100 Watts	No. 310A - 100 Watts No. 310B - 250 Watts
Single Tone Level	-6 db*	-1 db
Program Level	-12 db	-7 db

*Zero Level reference is 6 milliwatts.

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UNIT NO. 4	RCA 1 KW AND 5 KW TRANSMITTERS	LESSON NO. 8

SHORT & TALL

.....lean and fat.

If you were to personally call on one hundred highly paid executives, you would quickly discover that earning power and ability cannot be judged by outside appearances. Some of the executives to whom you talked would be tall and slim; others, short and fat. Some would be dressed immaculately, and others might have baggy trousers. But regardless of their outside appearance, inside of them they have what it takes to get to the top---mainly: foresight, backbone, and knowledge.

Regardless of the type of work a person selects to follow, he too, must have the same characteristics if he is to rise above the thousands and thousands of people who are destined to travel through life in the low-pay brackets. Therefore, it should be very encouraging for you to know that you have given excellent indications of having what it takes to get to the top. Conclusive proof that you have foresight was indicated when you enrolled for training in an industry which is expanding and growing from day to day. The fact that you are sticking to your studies is an excellent indication that you have backbone. And as you continue to progress, you will constantly be adding to your storehouse of knowledge, the third essential of success.

So, regardless of whether you be lean or fat, short or tall, you too, inside of you, have what it takes to win.

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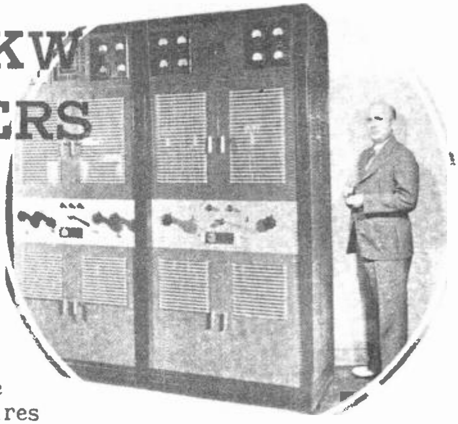
Lesson Eight

R.C.A. 1 & 5 KW TRANSMITTERS



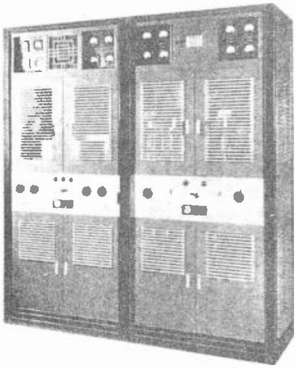
"I am going to devote this entire lesson to a description of the RCA 1 KW and 5 KW broadcast transmitters. The transmitters herein described are in use in several broadcasting stations. I want you to study these circuits and adjustment procedures very carefully; the knowledge you gain will greatly enhance your ability as a commercial operator. If you are intimately familiar with these transmitters, you will have no difficulty in immediately comprehending the operation of other RCA commercial transmitters.

"In the first part of the lesson, I shall describe the "exciter" unit, which may be converted for several types of operation. It can be used as a separate transmitter, as an exciter of the 1 KW amplifier, or as an exciter for the 5 KW amplifier. The expression "exciter" means that part of the complete transmitter wherein the elementary RF stages are contained; namely the oscillator, buffer, and low-power RF amplifiers, together with the necessary power supply and audio equipment.

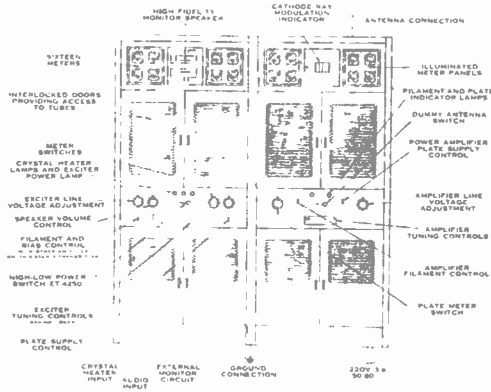
"When studying these transmitter circuits, watch the circuit diagrams very carefully, checking each statement in the text by locating the part on the diagram to which reference is made in the circuit description. After studying the lesson material at least three times, you should be sufficiently familiar with the transmitters to talk freely about the design of the equipment. This qualification will undoubtedly be a great asset when interviewing a prospective employer".

1. DESCRIPTION OF APPARATUS IN ET-4241 EXCITER

(A) General. A schematic diagram of the Type 1-D 1000-Watt Broadcast Transmitter is shown in Fig. 1. The ET-4241 exciter unit comprises all except the power amplifier stage and associated equipment. This diagram shows the essential equipment in the order in which the radio frequency carrier is generated by a precision crystal controlled oscillator, amplified by the buffer, first and second radio frequency amplifier stages, and by the power amplifier in which the radio frequency carrier is modulated by the audio frequency from the Class "B" modulator and then transferred by means



(A)



(B)

Fig. 2 (A) Photograph showing front of 1-D Transmitter. (B) Labeled drawing of front panel on 1-D Transmitter.

of a suitable coupling circuit to the antenna.

The audio frequency input is amplified by two push-pull transformer coupled Class "A" stages and a Class "B" modulator which is transformer-coupled to the radio frequency power amplifier. This system of modulation used is ordinarily designated as high-level modulation.

The bias voltages of the oscillator, buffer, first r-f amplifier, second r-f amplifier, and r-f power amplifier tubes are supplied by the flow of the DC grid current through the grid resistors. The 843 audio amplifier is biased by the voltage drop across the resistor connected between the cathodes and ground through which the DC plate current flows. The push-pull 845 driver stage is biased by the single phase full-wave copper oxide rectifier.

Adequate protection is afforded the operating personnel as all tuning dials and switches are grounded and safety switches remove all high voltage from the transmitter when the front panels are opened. The vacuum tube, power and control circuits are protected by fuses and overload and time delay relays.

The ET-4241 unit may be used as an exciter for either a 1-KW amplifier (as in the 1-D transmitter), or a 5-KW amplifier (as in the 5-C transmitter). With a few circuit alterations and a change in the tube sequence, the exciter may be used as a 100-watt, or as a 100/250 watt transmitter. In the latter cases, the unit is designated as the ET-4250 transmitter.

A photograph of the front of the complete 1-D transmitter is shown in Fig. 2; and labeled open views are shown in Figs. 3 and 4.

(B) Crystal Oscillator. The UL-4252-A Crystal Oscillator Unit, with an extremely low temperature coefficient crystal, is incorporated in this transmitter to maintain the assigned frequency within the limit of plus or minus 10 cycles. The crystal oscillator unit consists of two oscillators, each complete with an RCA-843 tube, tank tuning capacitor, tank coil, frequency vernier capacitor and plug-in crystal chamber housed in a single unit, which is mounted

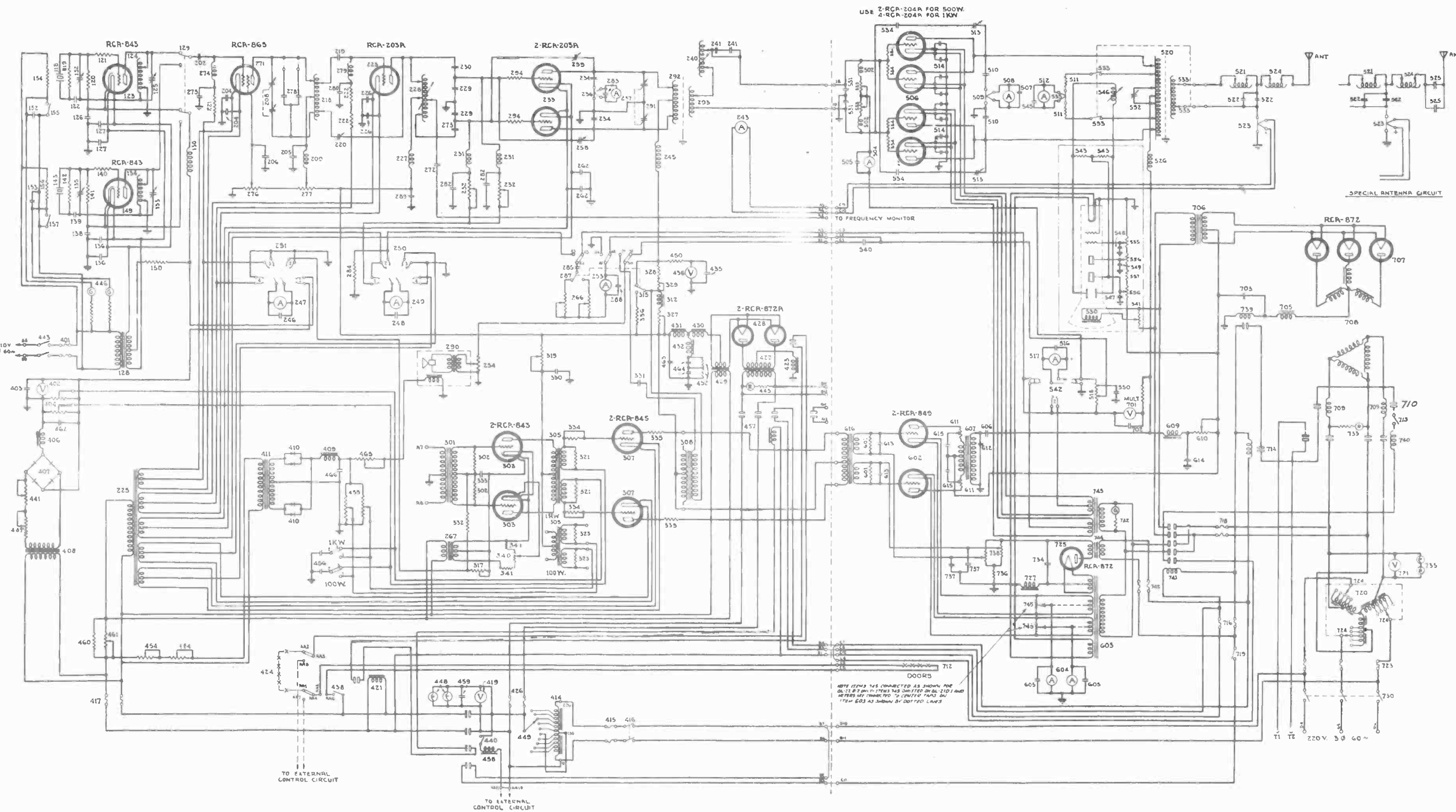


Fig.1 Schematic diagram of RCA type 1-D 1 KW Broadcast Transmitter.

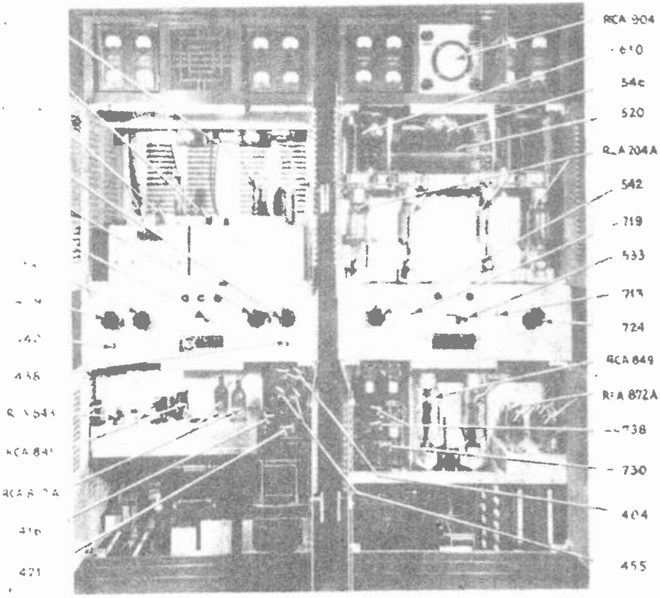


Fig.3 Open front view of 1-D with item numbers.

in place by means of a plug and jack arrangement on the front left side of the upper compartment. The plug-in crystal chamber is complete in itself, containing a crystal holder, heater and non-adjustable thermostat. The heater is used only to limit the crystal temperature from extreme variations.

In case of failure of the operating oscillator, the spare oscillator may be quickly connected in the transmitter by means of the switch which protrudes through the top of the unit.

The crystal oscillator circuit consists essentially of a crystal-controlled Hartley oscillator circuit. The quartz crystal, Item 118, (refer to Fig. 1) is connected in series with the DC voltage, blocking condenser, Item 122, and grid excitation portion of the coil Item 124. The amount of grid feedback is determined by the tapped ground connection on the coil, Item 124, and should be small so that the crystal frequency is the controlling factor.

Grid bias on the oscillator tube is maintained by the voltage drop across the gridleak, Item 120, through which the DC grid current flows.

The cathode of the oscillator tube is supplied with a negative 200 volts, while the plate is at DC ground potential. This negative voltage is supplied by the copper oxide rectifier unit, Item 407, through the associated filter circuit and meter switch, Item 251 to the cathode. The oscillator tube plate current is indicated by the meter, Item 247, which is connected into the circuit by the meter switch, Item 251.

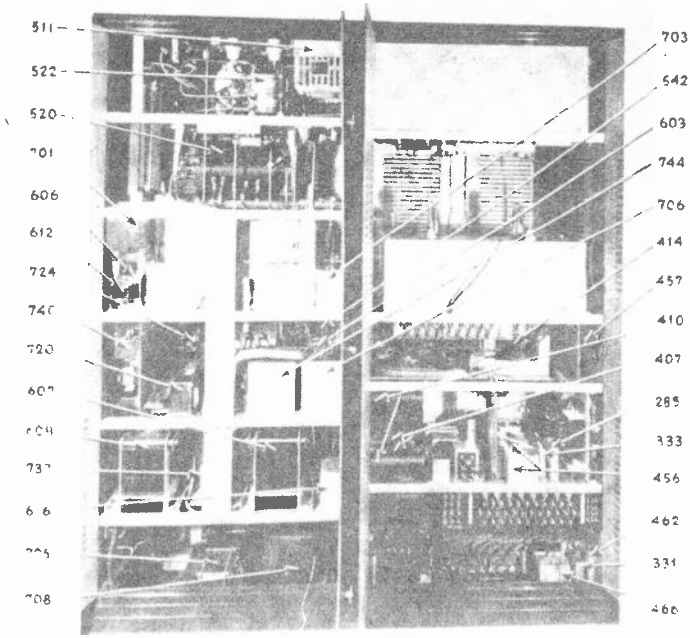


Fig.4 Open rear view of 1-D with item numbers.

The filament voltage of the oscillator tubes is supplied by a transformer, Item 128.

The exact frequency as assigned by the Federal Communications Commission can be obtained by operation of the frequency vernier capacitor, Item 132. This capacitor is controlled by a screw driver adjustment from the front of the crystal unit. A reliable frequency monitor or measuring equipment must be used in order to adjust the frequency by this method. This frequency adjustment may be used in the initial installation of the transmitter and also in the event that the crystals or circuit conditions are changed.

(C) Buffer Amplifier. The buffer amplifier utilizes an RCA-865 tube, which is coupled to the oscillator by means of the coupling condenser, Item 202. This stage is self-biased and the proper grid bias voltage is maintained by the flow of the DC grid current through the grid resistor, Item 221.

The DC plate voltage of the buffer amplifier is supplied by the full-wave single-phase mercury vapor rectifier, through a resistance, Item 277, and radio frequency choke, Item 209, to the tank coil, Item 218. The screen grid voltage is obtained from the same source through the resistor, Item 276. The plate current of the buffer amplifier tube is indicated by the meter, Item 247, which is connected into the proper circuit by the meter switch, Item 251.

The output circuit of the buffer amplifier is tuned to the crystal oscillator frequency and consists of a split stator variable condenser, Item 208, two fixed condensers, Item 278, and a tapped coil, Item 218. The center of the output circuit is at ground potential to the radio frequency voltage in order that the neutralizing voltage of the first intermediate amplifier will be in phase opposition to the grid exciting voltage.

(D) First Radio Frequency Amplifier. The grid of the first amplifier tube, RCA-203-A, is coupled to the output circuit of the buffer amplifier through the coupling condenser, Item 219. Grid bias for this stage is obtained by the flow of the DC grid current through the grid leak resistance, Item 222.

The DC plate voltage is supplied by the full-wave, single-phase rectifier, through the radio frequency choke, Item 227, to the center tap of the output coil, Item 228. The plate current of the amplifier tube is indicated by the meter, Item 247, which is connected into the proper circuit by the meter switch, Item 251.

The output circuit is a closed resonant circuit, consisting of a tapped coil, Item 228, with an adjustable short-circuited copper ring or "flipper" mounted inside of it for fine tuning purposes, and fixed condensers, Items 229, 230, and 273. The center of the output circuit is at ground potential to the radio frequency voltage in order that the proper voltage phase relation may be obtained to properly excite the push-pull power amplifier stage.

(E) Second Radio Frequency Amplifier. The radio frequency amplifier stage utilizes two RCA-203-A tubes connected in push-pull for 100 watts output and four RCA-203-A tubes connected in push-pull for 100/250 watts output. Two 203-A tubes are used in the ET-4241 Exciter. The two grid circuits of this stage consist of a radio frequency choke, Item 231, connected in series with the grid resistor, Item 232, and the meter switch to ground. The total direct current that flows in both grid circuits is indicated by the meter, Item 249, when the meter switch, Item 250, is in the proper position.

The grid bias for the second radio frequency amplifier stage is supplied by the voltage drop across the grid resistance, Item 232, developed by the flow of the DC grid current. The DC plate voltage is supplied by the single-phase full-wave rectifier. The total DC plate current is indicated by the meter, Item 249, when the meter switch, Item 250, is in the proper position.

The amplifier stage is cross-neutralized by means of the variable condensers, Items 258 and 259. The output circuit consists of two fixed condensers, Item 234, a variable tuning condenser, Item 291, and the primary of the radio frequency transformer, Item 292. The radio frequency tank current indicated by the meter, Item 237, with the associated thermo-couple, Item 236.

(F) Audio System. The audio system in the ET-4250, 250-Watt Transmitter consists of two RCA-843 tubes in the first audio stage, two RCA-845 tubes as drivers and two RCA-838 tubes as modulators. The audio tube complement of the ET-4240, 100-Watt Transmitter and ET-4241 5 KW Exciter consists of two RCA-843 tubes in the first audio stage and four RCA-845 tubes as modulators. The

ET-4241 1 KW Exciter employs two RCA-843 tubes in the first audio stage and two RCA-845 tubes in the second audio stage as drivers for the modulator tubes in the 1 KW Amplifier.

(G). First Audio Frequency Amplifier. The audio input voltage is applied to the primary of the audio transformer, Item 301, and then to the grids of two RCA-843 tubes in push-pull operated Class "A" in the ET-4240 100-Watt and ET-4250 100/250-Watt Transmitters and ET-4241 1 KW and 5 KW Exciter. The plate connections of the first audio tubes to the transformer, Item 305, are made to terminals in the position marked "1 KW" position. The tubes are automatically biased by the flow of the DC plate current through the resistance, Item 317, connected between the cathode and ground. The plate voltage is supplied by the single-phase, full-wave rectifier through the voltage dropping resistance, Item 319, to the center tap of the primary of the interstage transformer, Item 305. The plate current of the first audio amplifier tubes is indicated by the meter, Item 247, which is connected into the proper circuit by the meter switch, Item 251. The filament voltage is supplied by the transformer, Item 267. The audio input system is designed to operate from a 500-ohm circuit.

(H) Second Audio Frequency Amplifier. The second audio amplifier consists of four RCA-845 tubes connected in push-pull and operated Class "B" in the ET-4240 Transmitter and ET-4241 5 KW Exciter, two RCA-845 tubes in push-pull operated Class "A" in the ET-4241 1 KW Exciter and ET-4250 Transmitter. The grid connection to the transformer, Item 305, is made to the terminals in the position marked "1 KW". The bias voltage is supplied by the copper oxide rectifier, Item 407, and the bias voltage of each tube may be controlled separately by means of the potentiometers, Item 404, marked "Bias Pot. Second Audio Amp.", located on the switch panel. The plate voltage is supplied by the full-wave rectifier and the plate current of the tubes is indicated by the meter, Item 249, which is connected into the proper circuit by the meter switch, Item 250. The output circuit of the audio amplifier consists of the modulation transformer, Item 308, coupling condenser, Item 331, and modulation choke, Item 312, in the 100-Watt Transmitter and 5 KW Exciter, Transformer, Item 616 (which is located in the AA-4251 Amplifier Unit) in the 1 KW ET-4241 Exciter, and Transformer, Item 337, (which is not shown) in the 250-Watt Transmitter.

(I) Rectifiers. The plate voltages of the entire ET-4241 Exciter Unit, with the exception of the oscillator tubes, are supplied by two RCA-872-A hot cathode, mercury vapor tubes connected in a single-phase full-wave circuit. The filament voltage of the rectifier tubes is supplied by the transformer, Item 429, and the plate voltage by the transformer, Item 427. The filter circuit consists of the reactors, Items 430 and 431, filter condenser, Item 463, and a circuit resonated at 120 cycles, comprising the reactor, Item 432, condensers, Item 464, and resistance, Item 452. The rectified voltage is indicated by the meter, Item 436.

The copper oxide rectifier element, Item 407, which is connected in a full-wave circuit, supplies the DC voltage to the plates of the oscillator tubes and grid bias to the second audio amplifier tubes in the ET-4241 Exciter. The rectified voltage is controlled by the resistance, Item 441, and the grid voltage of the amplifier tubes by the potentiometers, Item 404. The plate voltage of the oscillator tubes is indicated by the meter, Item 402.

The copper oxide rectifier, Item 410, which is connected in a single-phase full-wave circuit, supplies the loudspeaker field voltage and bias voltage for the modulator tubes in the ET-4240 and ET-4250 Transmitters. The rectified voltage is controlled by the resistors, Item 454. The modulator bias voltage is adjusted by the potentiometers, Item 455.

(J) Monitoring Circuit. The monitoring loudspeaker, Item 290, is energized by means of the audio voltage developed across the potentiometer, Item 254, and the modulation meter by the audio voltage across the resistor, Item 284, through which the power amplifier plate current flows.[1] The loudspeaker volume may be controlled by the potentiometer, Item 254. The modulation meter may be calibrated by adjusting the resistance, Item 266.

2. *OPERATING PROCEDURE AND MAINTENANCE*

(A) General. 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 should be checked and their temperatures recorded.

To secure continuous and reliable operation, it is recommended that a definite maintenance schedule be arranged. It is of importance that the transmitter be kept free of dust. A small blower may be used to clean out inaccessible parts. The meter panels may be cleaned by removing the meter panel light support and inserting a cloth-covered stick through the opening. The transmitter should be inspected periodically for loosened and broken connections. As far as possible, anticipate tube failures by keeping a log and make the required tube replacements.

(B) Control Equipment. The contact tips of all contactors and relays should be kept smooth and clean. All connections should be checked for tightness and the mechanism checked for smoothness of operation.

(C) Radio Frequency Circuits. All the tubes should be removed periodically and the tube prongs and sockets cleaned. Clean and tighten all tank coil clips and connections. Variable condensers should be kept free of dirt with an air blast. Isolantite insulators should be wiped with a dry cloth.

(D) Power Circuits. The jaws and blades of the tap changing and line switches should be lightly coated with vaseline. All fuses and fuse clips should be kept clean and bright.

(E) Antenna. It is important that antenna insulators be kept clean to reduce high resistance ground leaks which will decrease the radiation efficiency of the station. Also clean the

[1] Refers to operation of the equipment as 100 or 250 watt separate transmitter. Does not apply when used as a 1 KW exciter.

lightning protection switch contacts and tighten all ground and antenna connections.

(F) Tube Complement.

	TYPE ET-4240 100-WATT TRANSMITTER	TYPE ET-4250 250-WATT TRANSMITTER	TYPE ET-4241 EXCITER UNIT (1-D Trans.)	TYPE ET-4241 EXCITER UNIT (5-C Trans.)
Oscillators..................	2-RCA-843	2-RCA-843	2-RCA-843	2-RCA-843
Buffer Amplifier............	1-RCA-865	1-RCA-865	1-RCA-865	1-RCA-865
1st R-F Amplifier...........	1-RCA-203A	1-RCA-203A	1-RCA-203A	1-RCA-203A
2nd R-F Amplifier...........	2-RCA-203A	4-RCA-203A	2-RCA-203A	2-RCA-203A
1st Audio Amplifier..........	2-RCA-843	2-RCA-843	2-RCA-843	2-RCA-843
2nd Audio Amplifier..........	4-RCA-845	2-RCA-845	2-RCA-845	4-RCA-845
Plate Voltage Rectifier......	2-RCA-872A	2-RCA-872A	2-RCA-872A	2-RCA-872A
3rd Audio Amplifier..........		2-RCA-838		

(G) Power Consumption.

	NO MODULATION	100% MODULATION
ET-4240 100-WATT Transmitter......	1.65 KW	1.85 KW
ET-4250 250-WATT Transmitter......	1.80 KW	2.10 KW
ET-4241 1-D Exciter Unit..........	1.65 KW	

(H) Table Of Typical Meter Readings.

	TYPE ET-4240 100-WATT TRANSMITTER	TYPE ET-4250 250-WATT TRANSMITTER 100-W	TYPE ET-4250 250-WATT TRANSMITTER 250-W	TYPE ET-4241 EXCITER UNIT (1-D)	TYPE ET-4241 EXCITER UNIT (5-C Trans.)
Line Voltage (volts)..........	110	115	115	110	110
Oscillator Plate Voltage (volts).......................	250	250	250	250	250
Oscillator Plate Current (ma.).........................	10-20	10-20	10-20	10-20	10-20
Buffer Amplifier Plate current (ma.)....................	20-40	20-40	20-40	20-40	20-40
First R-F Amplifier Plate current (ma.)................	50-100	50-100	50-100	50-100	50-100
Second R-F Amplifier (indirect measurement of output).	200	286	417	200-300	200-300
Total Plate Current (direct measurement of output)(ma.)...	175-225	275-300	400-450	———	———
Second R-F Amplifier total grid current (ma.)...........	100-120	200-240	200-240	100-120	100-120
Second R-F Amplifier tank current (amp. r-f)............	.75-2.0	.5-1.5	.75-2.0	.5-2.0	.5-2.0
Second R-F Amplifier Plate Voltage (volts)...............	1000±20	700±20	1000±20	1200±50	900-1000
First Audio Amplifier total plate current (ma.)...........	90-95	95-105	95-105	95-105	95-105
Second Audio Amplifier plate current (ma.) per tube........	50	———	———	50	75-100
Third Audio Amplifier plate current (ma.) per tube........	———	40	40	———	———

3. TYPE AA-4251 1000-WATT AMPLIFIER

(A) DESCRIPTION OF APPARATUS.

(a) General. The type 1-D Broadcast Transmitter consists of the Type AA-4251, 1000-Watt Amplifier Unit with the Type ET-4241 Exciter Unit. A complete schematic diagram is shown in Fig. 1. The type AA-4251 Amplifier is a self-contained unit and is inductively coupled to the ET-4241 Exciter Unit. It consists of four RCA-204-A tubes in a balanced push-pull circuit and modulated amplifiers with associated input and output circuits, antenna coupling and harmonic

suppression circuits, two RCA-849 tubes as Class "B" modulators, bias and plate voltage rectifiers and protection and control circuits necessary for the operation of the amplifier. A cathode ray oscilloscope as a visual modulation indicator is included in the amplifier unit.

The plate voltage to the power amplifier and modulator tubes is supplied by a three-phase, half-wave rectifier utilizing hot cathode mercury vapor rectifier tubes.

The bias voltage of the Class "B" modulator tubes is supplied by a single-phase, half-wave rectifier utilizing a hot cathode mercury vapor rectifier tube.

The bias voltage of the power amplifier tubes is supplied partly by the flow of the DC plate current through a resistor connected from the center taps of the secondaries of the filament transformer to ground and partly by the flow of the DC. grid current through the grid resistors.

The control circuit of the amplifier unit is interconnected with that of the exciter unit so that the filament and plate voltages of the tubes in the amplifier unit cannot be applied until the filament and plate voltages in the exciter unit are turned on. All tuning controls and switches are grounded and safety switches remove all high voltage from the amplifier unit when the front or back doors are opened. Opening the doors in either unit will remove the high voltage from the entire transmitter. The vacuum tube, power and control circuits are protected by fuses, overload and time delay relays.

If the switches marked "FILAMENT VOLTAGE" and "PLATE VOLTAGE" on the amplifier control panel and the switch marked "PLATE VOLTAGE" on the exciter control panel are closed first, the entire transmitter will start automatically when the master control switch on the exciter control panel marked "TRANSMITTER START" is operated.

Meters are provided to indicate the plate current of each of the Class "B" modulator tubes, the total grid current, tank current, and plate voltage of the power amplifier tubes, line voltage and phantom (dummy) antenna current. With the meter switch in the proper position, the plate current meter will indicate the total plate current of the power amplifier tubes or the plate and grid current of each tube separately. Indicator lights on the control panel show when the bias and plate voltage rectifiers are energized.

Flexible cable drives remotely control the variable condensers in the radio frequency circuits as in the exciter unit.

(b) Power Amplifier. The location of all equipment may be found by the item numbers on the wiring diagram. Figs. 3 and 4 show open views to indicate the equipment location. The power amplifier stage utilizes four RCA-204A tubes in push-pull. The grid circuit is inductively coupled to the second radio frequency amplifier in the exciter unit by a tuned circuit which consists of the coupling coil, Item 293, and loading coil, Item 240, located in the exciter unit and fixed condensers, Item 531, located in the amplifier unit. The grid bias for each tube is supplied by the voltage drop across the grid resistances, Item 553, developed by the flow of the DC grid current and also the voltage drop across the resistance, Item 518,

produced by the total plate current. The resistances, Item 554, are connected in the grid lead to equally distribute the load. The total grid current of the power amplifier tubes is indicated by the meter, Item 504.

The filament voltage of the power amplifier tubes is supplied by the transformer, Item 743.

The plate voltage of 2,000 volts is supplied by the three-phase, half-wave rectifier through resistances, Item 610, modulation choke, Item 609, and radio frequency choke, Item 526, to the center tap of the tank coil, Item 520. The total plate current or the plate current of each tube is indicated by the meter, Item 517, when the meter switch, Item 542, is in the proper position. The plate voltage of the power amplifier tubes is indicated by the voltmeter, Item 701.

The power amplifier tubes are cross-neutralized by means of the variable condensers, Item 513.

The output circuit consists of the fixed condensers, Item 510, variable tuning condenser, Item 552, and the primary of the radio frequency transformer, Item 520. The total radio frequency tank current is indicated by the meter, Item 508, with the associated thermo-couple, Item 509.

The phantom antenna is connected across the tank coil by the switch, Item 533, which is located on the control panel, and consists of the resistance, Item 511. The phantom antenna current is indicated by the meter, Item 512. The switch, Item 533, connects the harmonic tank and antenna circuits at the same time that the phantom antenna is disconnected.

The antenna circuit consists of the secondary of the radio frequency transformer, Item 520, harmonic tank inductance, Item 521, antenna coupling capacity, Item 522, antenna loading inductance, Item 524, and antenna series condenser, Item 525.

The antenna current is indicated by the meter, Item 243, which is located in the exciter unit, with the associated thermo-couple, Item 523.

The cathode ray modulation indicator is inductively coupled to the power amplifier tank circuit by means of the coil, Item 546. The voltages of the different electrodes are supplied by the plate voltage rectifier and may be adjusted by the potentiometers, Item 555, 556, 557.

(c) Modulator. The third audio amplifier or modulator utilizes two RCA-849 tubes in push-pull operated Class "B" which are excited by the second audio amplifier in the exciter through the transformer, Item 616. The bias voltage of each tube is supplied by the half-wave rectifier, Item 725, and may be adjusted separately by means of the potentiometers, Item 738.

The plate voltage of 3,000 volts is supplied by a three-phase, half-wave rectifier, Item 707, and the plate current of each modulator tube is indicated by the meters, Item 604. The output circuit of the modulator consists of the modulation transformer, Item 607, coupling condenser, Item 606, and modulation choke, Item 609. The filament voltage of the modulator tubes is supplied by the transformer, Item 603.

(d) Bias Voltage Rectifier. The bias voltage rectifier

utilizes an RCA-872A hot cathode mercury vapor rectifier tube in a single-phase, half-wave circuit. The filament voltage of the rectifier tube is supplied by the transformer, Item 603, and the plate voltage by the transformer, Item 744. The filter circuit consists of the filter condenser, Item 734, and choke, Item 727. The rectifier is loaded by the potentiometers, Item 738, and resistor, Item 736.

(e) Plate Voltage Rectifier. The plate voltage rectifier utilizes three RCA-872A hot cathode mercury vapor tubes connected in a three-phase, half-wave circuit. The filament voltage of the rectifier tubes is supplied by the transformer, Item 706, and the high voltage by the transformer, Item 708. The filter circuit consists of the filter reactor, Item 705, and filter condenser, Item 703.

(f) Control and Power Circuits. The line switch, Item 730, controls the 220-volt, three-phase power supply to the amplifier unit. The line fuses, Item 723, protect the line equipment and auto-transformer, Item 720. The filament and bias voltage rectifier circuits are protected by the fuses, Item 742, the plate voltage rectifier by the overload relays, Item 709, and modulator and power amplifier tubes by the relay, Item 739.

A two-wire control system is used which is energized by the 220-volt supply circuit in the Type ET-4241 Exciter Unit. By operating the control switch on the amplifier control panel marked "filament voltage," a magnetic contactor applies to the proper transformers, thereby energizing the filaments of all tubes. At the end of 30 seconds, the time delay - relay in the exciter unit closes, energizing the transformer which supplies voltage for the high voltage of the bias rectifier. Thirty seconds later, the time delay-relay contacts, Item 714, are closed, the plate voltage rectifier may be energized by closing the switch marked "Plate Voltage" which operates the plate contactor.

The following is a detailed discussion of the control sequence for manual operation assuming that all switches are "Off":

1. Close switch marked "CRYSTAL HEATER," Item 443, on the switch panel in the lower compartment of the exciter unit. The indicator light on the control panel should glow, indicating that power is applied to the heater. Closing Item 443, also applies filament voltage to the oscillator tubes.
2. Close the "LINE" switch, Item 730, on the switch panel of the amplifier unit. This applies power to the tapped auto-transformer and the meter panel lamps in the amplifier should light. Adjust the auto-transformer switch Item 724, until the meter, Item 721, indicates 220 volts.
3. Close switch, Item 416, located on the fuse panel in the exciter unit. This applies power to the tapped auto transformer and should light the meter panel lamps in the exciter unit. Adjust the auto-transformer switch, Item 449, until the meter, Item 419, indicates 110 volts.

4. Close the switch marked "Filament Voltage", Item 719, located on the control panel of the amplifier unit.
5. Close the switch marked "Transmitter Start", Item 440, filament contactor, and apply power to all filaments in the exciter and amplifier units. Closing Item 440, also starts the time delay-relay, Item 421, which will withhold all plate voltages in the exciter unit and bias voltage in the amplifier unit for 30 seconds.
6. Operate the switch, Item 438, marked "Plate Voltage" on the panel of the exciter unit. This will close plate contactor, provided the time delay-relay contacts and doors are closed, thus applying plate voltage in the exciter unit, amplifier, bias voltage and energizing the time delay-relay, Item 714 in the amplifier unit.

   The time delay-relay, Item 714, will withhold all plate voltages for 30 seconds. The lamp, Item 732, indicates when the bias voltage rectifier is energized.
7. Operating the switch, Item 713, marked "Plate On", will energize the plate voltage rectifier in the amplifier unit.

   The lamp, Item 733, indicates when the plate voltage rectifier is energized.
8. The entire transmitter may be stopped by opening the switch marked "Transmitter Start." The DC overload relay, Item 739, removes the high voltage when an overload is caused by the power amplifier or modulator tubes.

   When the plate voltage rectifier is overloaded, the overload relays, Item 709, open their contacts and de-energize the plate contactor, Item 740, which removes the high voltage.

(g) Monitoring Circuit. The monitoring loudspeaker, Item 290, and modulation meter, Item 253, which are connected into the proper circuit of the amplifier unit by means of link switches, located on the transfer terminal board in the exciter unit and energized by means of the audio voltage developed across the resistor, Item 518, by the audio component of the power amplifier plate current. The frequency characteristic of the loudspeaker may be changed by adjusting the tap connection of the contactor, Item 550, on the resistor, Item 518, or it may be disconnected entirely.

(B) INSTALLATION.

The antenna lead-in insulator is located on the right-hand side of the amplifier unit and the main ground terminal on the left-hand side. The ground terminal should not be connected to the transmitter frame if a counterpoise or transmission line is used.

The 220-volt, three-phase supply leads should be connected to the proper terminals on the terminal board.

Connect two leads of ¼ inch O.D. copper tubing from the two terminal insulators located on the upper right-hand side of the exciter unit to the two terminal insulators located on the left of the power amplifier unit. These leads should be made as equal in length as possible.

Copper tubing, $\frac{5}{16}$ inch O.D., is recommended for the antenna lead-in connection.

Complete instructions pertaining to minor connections are supplied with the transmitting equipment.

4. ADJUSTMENT AND OPERATION

WARNING: NO ATTEMPT SHOULD BE MADE TO ADJUST OR OPERATE THE TRANSMITTER WITHOUT THE PROTECTIVE BACK AND SIDE SHIELDS IN PLACE. ALL SAFETY PRECAUTIONS SHOULD BE OBSERVED AS THE HIGH VOLTAGES EMPLOYED IN THE TRANSMITTER ARE DANGEROUS TO HUMAN LIFE. ALL VOLTAGES SHOULD BE REMOVED FROM THE TRANSMITTER BY THE PROPER CONTROL SWITCHES.

(A) Preliminary Test of Power Circuits and Apparatus. Before applying voltage to the Type AA-4251 Amplifier Unit, the ET-4241 Exciter Unit should be adjusted. Adjust the resistance, Item 319, until the plate voltage of the first audio amplifier tubes is 425 volts and adjust resistance, Item 317, until the plate current is approximately 50 milliamperes. The plate voltage of the second audio frequency amplifier tubes will be approximately 1,200 volts. Adjust the bias voltage potentiometer, Item 404, located on the switch panel, until the plate current of each of the second audio amplifier tubes is approximately 55 ma.

Adjust the AC overload relays, Item 709, in the amplifier unit for 16-20 amperes, removing the dashpot and changing the depth of the plunger according to the scale marked on it.

The DC overload relay, Item 739, should be adjusted for 2.0 amperes. No oil is used in this relay.

The time delay-relay, Item 714, should be adjusted so that its contacts close approximately 30 seconds after the "Transmitter Start" switch has been operated. The dashpot should be filled with oil. The operating time may be varied by adjusting the depth of the plunger or varying the number and size of holes in the plunger cup by turning the disc in the bottom of the cup.

Open the line switch, Item 730, and insert the following 250-volt cartridge fuses in the cutouts provided.

Item 723, power supply line, 20 amperes.
Item 718, filament circuit, 6 amperes.
Item 716, control circuit, 6 amperes.

Do not insert the high-voltage fuses.

Close the line switch, Item 730, and adjust the amplifier line voltage switch, Item 724, until the line voltage is 220 volts as indicated by the line voltmeter, Item 721. Close the switch marked "FILAMENT VOLTAGE" and check the filament voltage at the socket terminals as indicated in the following table:

Power Amplifier, RCA-204A tubes, 11 volts, ±2%.
Modulator, RCA-849 tubes, 11 volts, ±2%.
Bias Rectifier, RCA-872A tubes, 5.0 volts, ±2%.
Plate Rectifier, RCA-872A tubes, 5.0 volts, ±2%.

If the filament voltages are not within the correct limits, the line voltage should be readjusted. This line voltage should be noted and used. Heat the tube filaments for 15 minutes.

Adjust the bias potentiometers for maximum voltage by turning them to the right as far as possible.

(B) Tuning and Neutralizing Adjustment. Apply the high voltage to the exciter unit and resonate the grid coupling circuit of the amplifier unit for maximum power amplifier grid current as indicated by the meter, Item 504, by adjusting the taps on the loading coil, Item 240. When the tap resulting in the maximum grid current is found, the fine adjustment should be made by varying the position of the "flipper" in loading coil, Item 240. The position of the "flipper" should be 45 degrees rather than vertical or horizontal. If no grid current is indicated by the meter, Item 504, tighten the coupling between the second radio frequency amplifier and the power amplifier by moving the position of the coupling coils in the exciter unit. Each adjustment of the coupling coil should be followed by a readjustment of the "flipper" for maximum grid current. If it is impossible to tune the grid coupling circuit above 1,000 kilocycles, connect the loading coil, Item 240, in parallel with the coupling coils in series or the coupling coils (in parallel) in series with the loading coil.

After the grid coupling circuit has been resonated, reduce the grid current to a low value by moving the coupling coil, and couple a 115 ma. thermo-galvanometer, or a low-reading r-f milliammeter to the power amplifier tank circuit. Adjust the neutralizing condensers, Item 513, for minimum capacity.

If no current is indicated by the thermo-galvanometer, adjust the position of the coupling coils. Vary the turns in the plate tank inductance, Item 520, for a maximum reading of the thermo-galvanometer. The fine adjustment for tuning the tank circuit should be made by varying the variable condenser, Item 552, which should be connected across one-half to three-quarters of the active turns of the tank coil. If the tank current exceeds the maximum reading of the thermo-galvanometer, the current should be reduced by partially neutralizing the power amplifier stage by increasing the capacity of the neutralizing condensers, Item 513. The neutralizing condensers should be rotated simultaneously, keeping the adjustments the same as nearly as possible. After the tank circuit has been properly tuned, the neutralizing condensers, Item 513, should be carefully adjusted for complete neutralization as indicated by a minimum or zero reading of the thermo-galvanometer.

Now increase the total power amplifier grid current to approximately 240 to 280 milliamperes by moving the grid coupling coils, and retune the grid input circuit. The tank circuit should be resonated again by adjusting the tuning condenser, Item 552, and re-neutralized.

Adjust the variable grid resistors until the grid voltage of the power amplifier tubes is 275 to 300 volts with the correct grid current. The correct grid excitation may be obtained accurately by adjusting the plate voltage of RCA-203A power tubes in the exciter unit by means of the rheostat, Item 327.

Connect the dummy antenna into the tank circuit by throwing the switch, Item 533, to the proper position. Apply the high voltage to the exciter and amplifier units. Adjust the bias voltage potentiometers, Item 738, until the plate current of each RCA-849 modulator tube is approximately 45 to 55 milliamperes. Adjust the resistance, Item 610, by shorting out resistor units, until the plate voltage is 2,000 ±20 volts and adjust the position of the dummy antenna connections on the tank coil, Item 520, until the total amplifier plate current is 835 ma. Tune the power amplifier tank circuit for a minimum indication of the plate current meter, Item 517, by varying the tuning condenser, Item 552. Adjust the grid coupling coils until the total grid current of the power amplifier tubes is within the limits specified. Throw the switch, Item 533, to the "ANTENNA" position. As the antenna circuit is not yet tuned and is loosely coupled to the power amplifier, plate current will be lower than normal. When the antenna is properly tuned and coupled, however, the power amplifier plate current will increase to normal and a slight retuning of the variable tank condenser, Item 552, will be required for resonance.

(C) Antenna Tuning. The plate voltage must be removed for each adjustment on the antenna circuit. Resonance is indicated in the antenna circuit by a maximum reading of the meter, Item 243, and in the harmonic tank by a minimum indication of the power amplifier tank current meter, Item 508. A meter may be inserted in the harmonic tank circuit, in series with the harmonic suppression coil, Item 521, for tuning purposes and resonance will be indicated by a maximum reading of this meter.

The antenna current at the full-power output of the transmitter may be calculated from the equation:

$$I_A = \sqrt{\frac{W}{R_A}}$$

Where: I_A = antenna current in amperes,
W = antenna power in watts,
R_A = antenna resistance at the operating frequency.

If the operating power is to be determined by the indirect measurement method, the number of turns in the coupling coil should be adjusted until the total plate current of the power amplifier tubes is 835 milliamperes with a plate voltage of 2,000 volts.

The capacity of the coupling capacitors, Item 522, in order to terminate the transmitter into the proper impedance, is determined by the antenna resistance and reactance. It is necessary in order to properly tune the antenna coupling circuit that the antenna circuit, which includes the antenna coil, Item 524, and antenna, be inductive. If the antenna reactance is capacitive enough, turns should be used in the antenna coil, Item 524, until the antenna circuit has an inductive reactance, 150 to 250 ohms. If the antenna reactance is inductive, it will be necessary to use only a few turns in the antenna coil. However, the attenuation of the r-f harmonics will be greater if the inductance of both the antenna coil, Item

524, and the harmonic suppression coil, Item 521, are as large as possible with the antenna coupling circuit properly tuned. Connect about half of the turns in the antenna coil and resonate the circuit by adjusting the number of turns in the harmonic suppression coil, Item 521, and antenna coupling coil, Item 520, for a maximum indication of the antenna meter and the correct power amplifier plate current.

If the circuit does not resonate within the range of the harmonic suppression coil, the number of turns in the antenna coil should be changed.

After the antenna coupling circuit has been resonated, retune the power amplifier tank circuit. If the antenna coupling circuit has been properly coupled to the power amplifier tank circuit, the plate currents of the power amplifier tubes should be approximately equal and within the limits specified in the chart, with the correct plate voltage.

(D) Dummy Antenna Adjustment. Throw the switch, Item 533, to the position marked "PHANTOM ANTENNA" and adjust the phantom antenna tap connections symmetrically, with respect to the center tap on the power amplifier tank inductance until the total plate current of the power amplifier tubes is of the same value as when the antenna circuit is connected. The total resistance of the phantom antenna is approximately 2,640 ohms. The phantom antenna current, as indicated by the meter, Item 512, may be determined by the same equation used for calculating the antenna current.

TABLE OF TYPICAL METER READINGS

	TYPE AA - 4251 1 KW AMPLIFIER 1000 WATTS OUTPUT
Power Amplifier Total Grid Current (ma.)........	200-280
Power Amplifier (indirect measurement of output)(ma.)..................................	835
Total Plate Current (direct measurement of output)(ma.)................................	800-875
Power Amplifier Tank Current (amp. r-f).........	2.5-4.0
Power Amplifier Plate Voltage (volts)...........	2000 ±20
Modulator Plate Current (ma.)(left).............	45-55
" " " " (right)...........	45-55
Line Voltage (Volts)............................	220 ±5

4. DESCRIPTION OF APPARATUS IN 5-C TRANSMITTER

(A) General. The RCA Type 5-C Broadcast Transmitter consists of three main units, the Type ET-4241 Exciter, the Type AA-4244 5 KW Linear Radio Frequency Amplifier and the Type AP-4242 Rectifier Unit. Each unit is completely shielded and is as self-contained as possible. In addition to the above, there is furnished an Antenna Tuning Unit, Type AZ-4243 or Type AZ-4272, which contains all necessary equipment for terminating the transmission line and tuning the antenna. A Cathode-Ray Modulation Indicator and Hum Compensator are mounted in a standard speech input cabinet rack. A photograph of the complete 5-C Transmitter is shown in Fig. 5.

TUBE COMPLEMENT

Oscillators	2-RCA-843
Buffer Amplifier	1-RCA-865
First R-F Amplifier	1-RCA-203A
Second R-F Amplifier	2-RCA-203A
Power Amplifier	2-RCA-863
Low-voltage Plate Rectifier	2-RCA-872A
High-voltage Plate Rectifier	12-RCA-872A
First Audio Amplifier	2-RCA-843
Second Audio Amplifier	4-RCA-845
Monitor Rectifier	2-RCA-217C

POWER REQUIREMENTS

(1) 220-volt, 3-phase, 3-wire, 60-cycle	32 KW
(2) 110-volt, 1-phase, 60-cycle	15 Watts

A schematic diagram of the complete transmitter is shown in Fig. 6. This diagram shows the circuit arrangement by which the radio frequency carrier is generated with a precision crystal-controlled oscillator, and amplified by the buffer and three radio frequency amplifiers.

The radio frequency carrier is modulated in the second r-f amplifier by a Class "B" modulator. The audio frequency input is amplified by a push-pull Class "A" driver stage followed by the Class "B" modulator, which is transformer coupled to the second r-f amplifier. The final r-f amplifier operates as a linear power amplifier.

Care has been taken to suppress r-f harmonic radiation. A balanced output circuit, together with a static shield placed between the power amplifier tank inductance and the antenna coupling coil, reduces to a minimum the harmonic energy transferred to the transmission line. To further reduce the harmonic radiation, a tuned circuit is used to terminate the transmission line and a static shield is included between the line tank and antenna coupling coils.

All the plate voltages, with the exception of that for the oscillator tube, are supplied by rectifiers utilizing hot cathode, mercury-vapor rectifier tubes. The plate voltage to the oscillator tube is supplied by a single-phase, full-wave, copper-oxide rectifier, which also supplies bias voltage to the second audio frequency amplifier or modulator.

All filaments are heated with alternating current from suitable transformers. In the 5 KW linear amplifier stage, the filament voltages are supplied 90 degrees out of phase.

The bias voltage of all r-f stages in the Exciter Unit is obtained by the flow of the DC grid current through the grid resistors. The proper grid bias voltage of the first r-f amplifier is developed partly by the flow of the DC grid current through the grid resistor and partly by the flow of the DC plate current through the resistor connected from the center tap of the secondary of the filament transformer to ground. The 5 KW Amplifier is biased by the voltage drop across separate cathode bias resistors. These are connected between the secondaries of the filament transformers and ground and carry the DC plate current. The Class "A" Audio Amplifier uses a cathode bias resistor connected from cathode to ground, the bias voltage of the Class "B" modulator stage is supplied by the single-phase, full-wave, copper-oxide rectifier. An additional copper-oxide rectifier energizes the field of the monitoring loudspeakers.

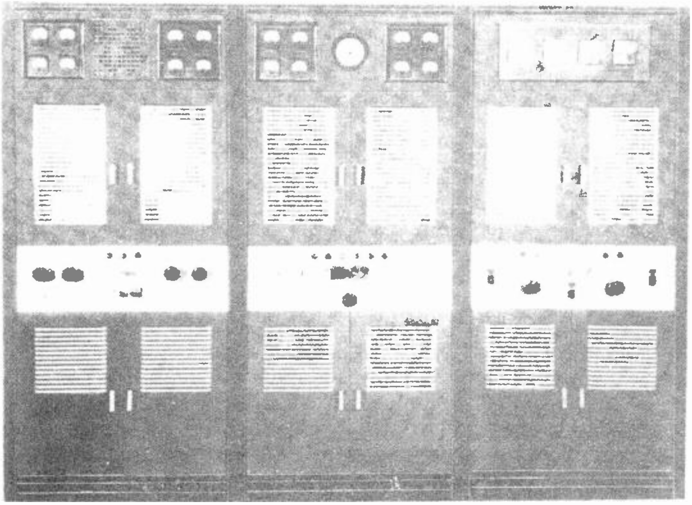


Fig.5 Photograph showing front of RCA type 5-C 5 KW Broadcast Transmitter.

Meters are provided to indicate the percentage of modulation, line voltage, plate voltage and currents, and tank and antenna currents.

The variable tuning elements of the radio frequency circuits are remotely controlled by flexible cable drives; the controls of which are grouped in recesses in the control panels. Knobs, which may be removed after the transmitter has been properly tuned and adjusted, are provided on the controls.

Indicating lights are located on the front control panel to show when the heater circuits of the crystal ovens are functioning properly and to indicate when the various control circuits are energized.

Adequate protection is afforded the operating personnel since all tuning dials and switches are grounded, while safety switches

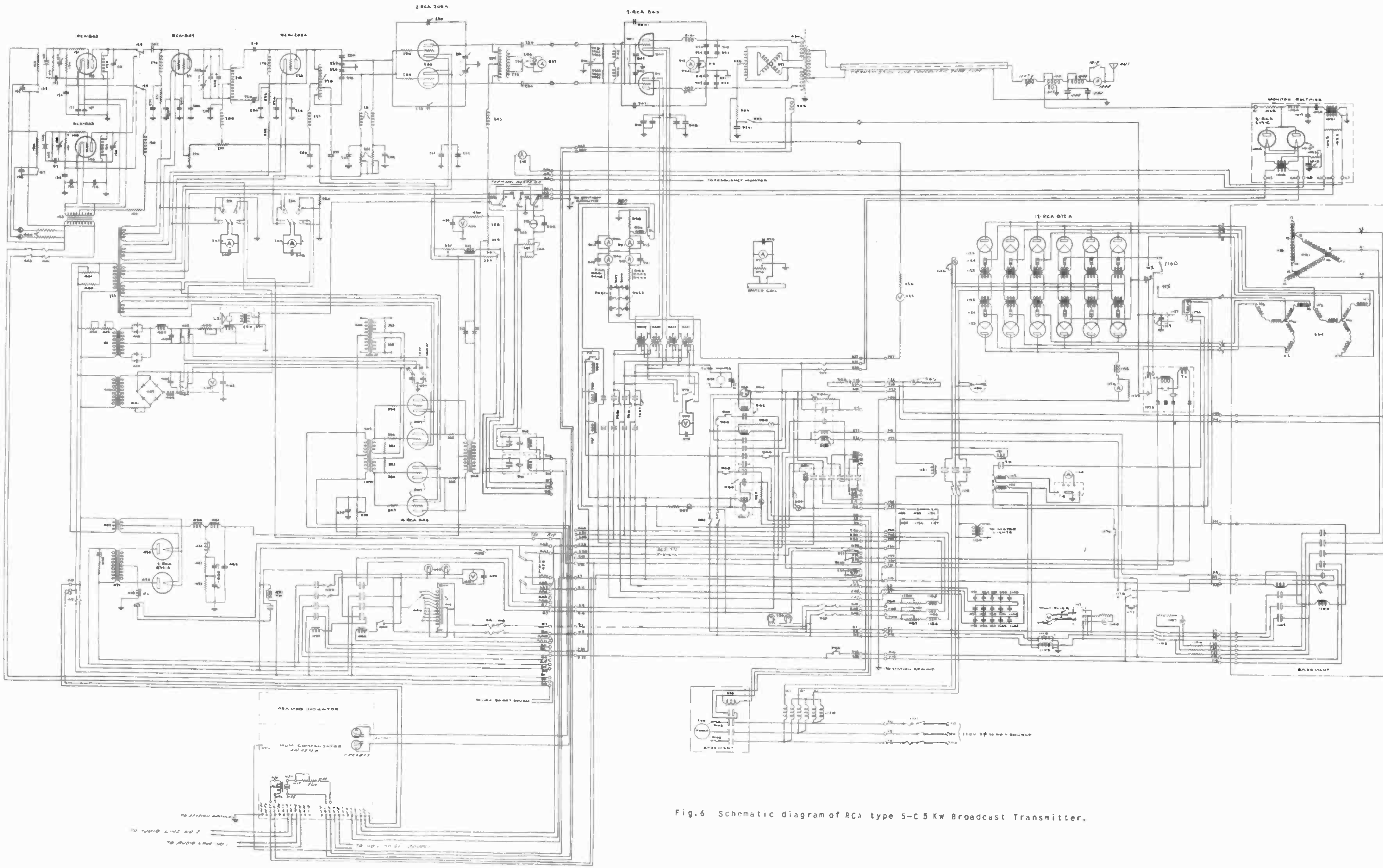


Fig.6 Schematic diagram of RCA type 5-C 5 KW Broadcast Transmitter.

remove all high voltage from the transmitter when the front panels are opened. The vacuum tube power and control circuits are protected by fuses, overload relays, and time delay relays. In the filament and power supply circuits of the 5 KW Amplifier, combination breaker and overload breakers are provided. These can be immediately reset by hand after opening, but cannot be held closed under overload conditions.

The control system is arranged so that starting may be entirely automatic, partly automatic, or entirely manual. For automatic operation, a sequence relay is provided which brings the transmitter back on the air twice after an overload, and in the event of a third failure, removes plate voltage from all stages. After any failure, the sequence relay can be restored to its normal position by pressing a reset button.

The line voltage is regulated to a constant value with an automatic induction regulator, which is mounted in the Rectifier Unit.

For stations operating on two different power outputs, a power change control system is provided. A 20,000-volt relay is mounted in the Rectifier Unit and changes the plate voltage on the final amplifier. The r-f input voltage on the final amplifier is changed by varying the plate voltage on the modulated amplifier. For this a 2,000-volt relay is provided in the exciter Unit. Control is made from a special switch on the amplifier fuse panel.

The position of all parts may be located by referring to the connection diagrams included in this lesson.

(B) 5 KW POWER AMPLIFIER. The 5 KW Power Amplifier utilizes the entire center section of the 5-C Broadcast Transmitter and is known as the Type AA-4244 5 KW Amplifier. The amplifier employs two UV-863 water-cooled tubes, connected in a balanced push-pull circuit. A tube capacity is thus provided which is capable of handling the 20 KW peak output during 100% modulation. The filament heating power is obtained from the alternating current power source by means of voltage-reducing transformers. The primary current to the transformers flows through a low-pass filter designed to remove high-frequency harmonic voltages present in the supply. The grid bias voltage is developed by the voltage drop across cathode resistors, Items 944 and 945, which are by-passed for audio frequencies with capacitors, Items 942-943 or 9421-9422. Separate resistors and capacitors are provided for each tube and fuses are connected in series with each capacitor to prevent the loss of bias voltage should a capacitor become defective. Radio frequency grid excitation is obtained directly from the modulated amplifier in the ET-4241 Exciter Unit. Proper coupling is obtained by connecting the UV-863 grids across two sections of the modulated amplifier tank capacitors, Items 902 and 903.

The plate tank consists of the fixed capacitors, Items 918 to 925, the tank inductance and transmission coupling coil, Item 930, and the variometer, Item 927. An ammeter, Item 912, and its associated thermo-couple, Item 913, are used to indicate the tank current. A small coil, Item 994, with adjustable coupling is located directly back of the plate tank inductance and provides a radio frequency pickup for the Hum Compensator Unit.

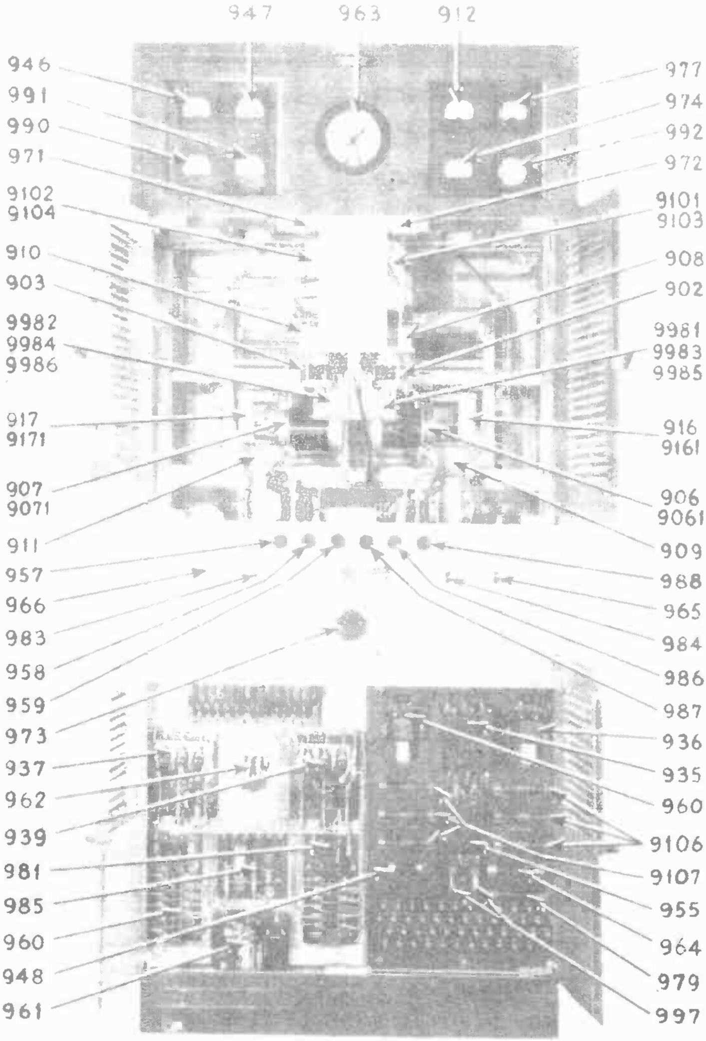


Fig.7 Open front view of 5 KW amplifier with item numbers.

Cross-neutralization is effected by means of the fixed mica capacitors, Items 906-907 or 9061-9071.

Indicating water interlocks are inserted in the outlet pipe from each tube and are located at the lower rear of the unit. A dial thermometer with an external bulb is located in the upper center of the control panel and indicates the temperature of the exhaust water from the two tubes. Should the water become too hot, the thermometer will make electrical connection and operate relay,

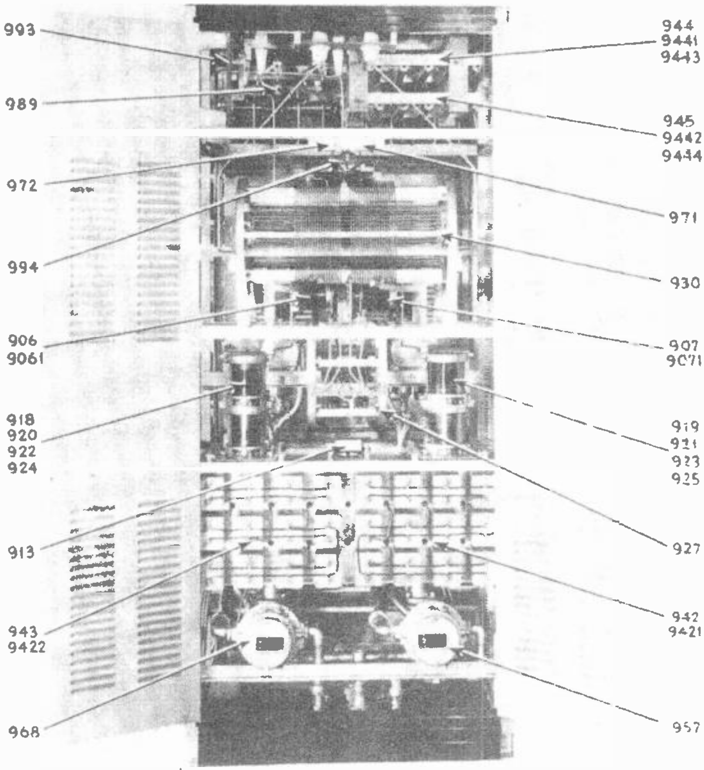


Fig.8 Open rear view of 5 KW amplifier with item numbers.

Item 962, thereby removing the plate voltage from the transmitter,

Insulated water columns are provided between the tube sockets and the water piping by running the inlet and exhaust water of each tube socket through coiled porcelain pipes, which are located beneath the tube sockets.

Indicating lamps are mounted on the front panel and show correct operation of the interlocking switches, water flow, filament voltage and plate voltage. An additional lamp shows when the overload relay has operated.

A tube hour meter, Item 992, is located on the front panel and is connected across one-half of the filament transformer primary. The dials are calibrated to record hours of operation. Tube record sheets should include tube hour references as indicated by this instrument. Figs. 7 and 8 will assist in locating the various parts in the AA-4424 5 KW Amplifier.

(C) HIGH VOLTAGE RECTIFIER.

(a) General. The high voltage rectifier for the 5 KW Am-

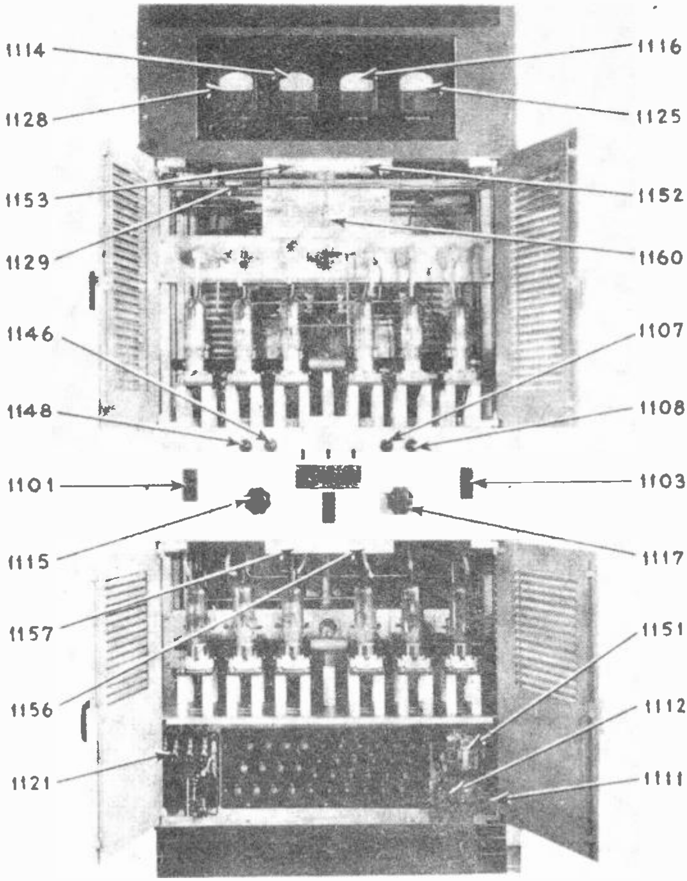


Fig.9 Open front view of 20 KW rectifier with item numbers.

plifier is contained in the right-hand section of the 5-C Transmitter and is known as the AP-4242 Rectifier Unit. In it are located the filter system and the twelve UV-872A rectifier tubes with their associated equipment. These parts may be located in Figs. 9 and 10.

Each rectifier tube is provided with a separate filament-heating transformer, Item 1122, and arc-back indicator, Item 1124. The primaries of the transformers are connected in such a manner as to equally distribute the load to each of the three phases of the power supply.

The operation of the arc-back indicator is shown by the telephone-type drop indicator mounted on the front of the unit, and is caused by a reversal of the direction of the current flow through the tube. An occasional indication does not necessarily identify a defective tube, but repeated and frequent operation indicates a

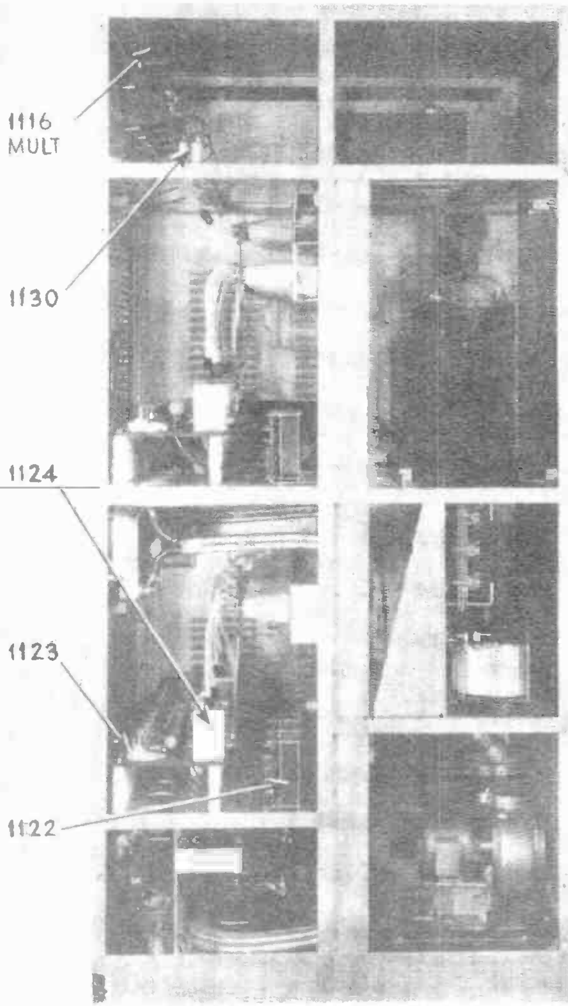


Fig.10 Open side view of 20 KW rectifier with item numbers.

defective rectifier tube which should be removed.

The circuit arrangement utilizes two secondaries in the high-voltage power transformer. Each secondary has its own six-tube, three-phase, full-wave rectifier. The center tap connection of each of the secondaries is brought out so that a one-half voltage connection can be made on each rectifier. The outputs of the two rectifiers are connected in series and leads brought from each rectifier and its one-half voltage connection to a link switch, Item 1160, so that four output voltages can be secured. Further adjustment of the high voltage may be made by taps on the primary of the power transformer. These taps will allow for a voltage reduction to 89.7% of the full secondary voltage.

The filter is of the choke input type and is comprised of three 2 mfd. capacitors connected in parallel to form a 6 mfd. capacitor, Item 1159, and a 5 henry reactor, Item 1158.

Meters located on the panel indicate the rectified output voltage and current. By means of switches, two additional meters indicate the line currents and voltage of the three-phase supply.

Indicating lamps show operation of the filament voltages, plate voltages, and interlock circuits. A low-pass filter is included in this unit for filtering the primary power to the power amplifier filament transformers. The capacitor section is divided so the capacitance can be readily varied. The capacitance used should be that giving the lowest carrier noise. Three resistors, Items 1180, 1181, and 1182, are connected in leads of the three-phase supply to the power amplifier filament transformers. These are used to balance the three-phase supply and adjust for correct filament voltage.

Also located in this unit is the air-blowing equipment. A small blower located in the lower rear section of the frame blows air through a distributing system composed of copper and bakelite piping. The exhaust is constructed to provide a blast of air on a single spot of each of the rectifier tubes. Thus, the spot will remain cool and provide a place for the condensation of mercury.

(b) Automatic Induction Voltage Regulator. The regulator, Item 1120, is used to automatically increase or decrease the voltage supply to the transmitter so as to compensate for the variable line voltage. The regulator consists of a fixed secondary winding and a movable primary winding; the movable winding is at rest, except when it is necessary to compensate for a change in voltage. The primary winding is connected to a motor that automatically starts and stops whenever line voltage correction is required. The complete regulator is mounted with the power transformer external to the transmitter.

(c) Power Transformer. The power transformer is located external to the transmitter. Two secondaries, each with staggered "Star" connections, and one tapped "Delta" connected primary are provided. The transformer is enclosed in an oil-filled iron case and is self-cooled.

The control circuit is connected so that low plate voltage is applied to the rectifier tubes for a few seconds before the full voltage. The voltage drop is accomplished by having resistors, Item 1106, in series with the primary leads of the plate transformer. As shown in the schematic diagram, these primary resistors are in the circuit when the contactor, Item 1104, closes, but are shorted out as soon as contactor, Item 1105, closes. Both the contactors are located external to the transmitter, generally near the plate transformer. The resistors are located in the main rectifier unit.

5. PRIMARY POWER, CONTROL AND PROTECTIVE CIRCUITS

(A) PRIMARY POWER CIRCUITS. The 220-volt, 3-phase, 60-cycle lines enter the transmitter in the Rectifier Unit and are distributed as shown in Fig. 11. The lines connect first to a thermal circuit breaker, Item 1101, which is located on the front panel of the Rectifier Unit. From this breaker, the power is divided between the water pump motor, Item 934, and an automatic induction voltage regulator, Item 1120. The output of the voltage regulator is divided into five circuits, four of which are supplied with circuit breakers; a fifth circuit carries all the primary power for the Exciter Unit and has a separate switch, Item 416, fuse, Item 415, and voltage-regulating, tapped auto-transformer, Item 414. All circuits, with the exception of the control equipment, contain individual contactors, which are operated by the control circuits.

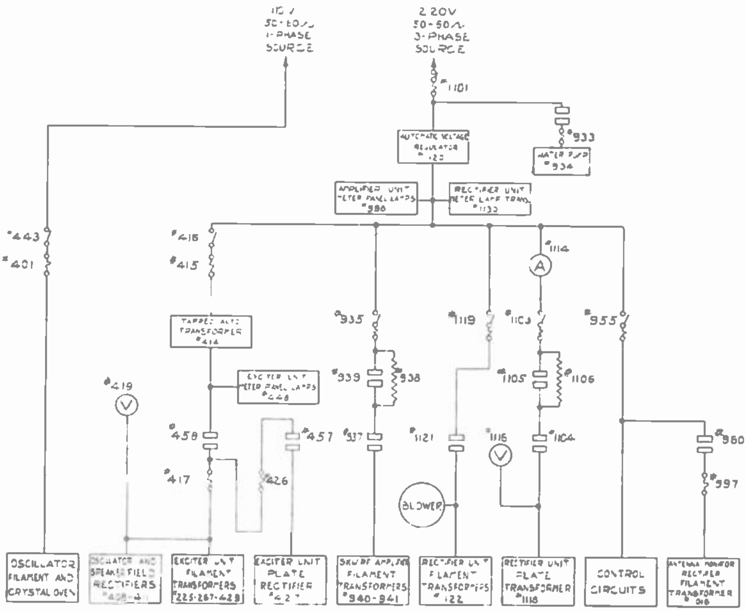


Fig.11 Block diagram of power circuits in 5-C Transmitter.

A separate 110-volt, 60-cycle, single-phase power supply is required for crystal oven heating and for the oscillator tube filaments. This circuit is separately controlled by switch, Item 443, and protected by fuse, Item 401.

Primary starting resistors are provided in the circuits to the 5 KW r-f amplifier tube filaments and the rectifier unit plate transformer. These resistors are shorted with contactors which operate with a time delay. This provides a lower starting voltage for the protection of the tubes and equipment.

All primary circuits that are not provided with circuit breakers are supplied with fuses.

(B) POWER METERING. In two of the three power lines to the main rectifier are current transformers, Items 1109 and 1110, which operate a single-phase ammeter, Item 1114, and overload trip relays, Items 1111 and 1112. The ammeter can be switched to two phases with the ammeter switch, Item 1115.

The line voltage to the primary of the main rectifier plate transformer is metered by a voltmeter, Item 1116, which reads one phase at a time. It can be switched into each phase in turn by a three-position voltmeter switch, Item 1117.

The voltage across the output of the auto-transformer in the Exciter Unit is indicated by a voltmeter, Item 419.

(C) PROTECTIVE CIRCUITS. Protection is afforded the equipment and operating personnel wherever possible. All doors are provided with interlocking switches, which remove all high voltage as soon as a door is opened. In addition, the opening of a door operates a shorting contactor, Item 1127, which discharges the filter capacitors for the high-voltage rectifier.

Overload relays remove the power supply as soon as the plate currents exceed the proper values. One overload relay, Item 423, protects the apparatus in the Exciter Unit; one, Item 950, the 5 KW amplifier tubes and two, Items 1111 and 1112, the primary of the high-voltage rectifier transformer. The use of two relays in the latter instance is necessary to provide protection in case of overload in any one phase.

The circuit breakers contain automatic tripping devices. Whenever the current exceeds the design limit, the breakers open and the handle travels to a central position. These breakers require a manual reset, which is accomplished by first returning the handle to the "OFF" position and then to the "ON" position. When not tripped, these breakers may be operated as ordinary switches. The "ON" position is indicated with a white line.

Water-cooled tube protection is accomplished by special apparatus and circuit connection, so arranged that all power is taken off the water-cooled tubes unless the proper flow of water is being obtained and the water temperature is a safe value. After turning off the transmitter, time-delay relay, Item 961, keeps the water-cooling system in operation for several minutes, until the tubes are thoroughly cooled.

(D) CONTROL CIRCUITS.

(a) General. Power for the operation of the control circuits is obtained by connecting across two leads of the three-phase supply. As shown in the block diagram for the power circuits, the entire control circuit system is supplied through a single circuit-breaker (955). The input to this breaker is taken directly from the output of the induction voltage regulator and, together with the entire transmitter, is completely disconnected from the power source when "LINE SWITCH", Item 1101, is open.

The operating sequence for the control circuit is shown in Fig. 11.

(b) Preliminary Operation. The following is a detailed dis-

cussion of the control circuit sequence, assuming all switches are "Off" and the "Reset" switch is set for "Manual" operation:

1. Close switch marked "CRYSTAL HEATER", Item 443, on the switch panel in the lower compartment of the Exciter Unit. The indicator light on the control panel should glow, indicating that power is applied to the heater. Closing Item 443 also applies filament voltage to the oscillator tubes.

2. Close the "LINE" switch, Item 1101, on the front panel of the rectifier Unit. This applies power to the automatic induction voltage regulator. The meter panel lamps on the Amplifier and Rectifier Units should light. The lamp marked "LINE" will also light.

3. Close the line switch, Item 416, located on the fuse panel in the Exciter Unit. This applies power to the tapped auto-transformer and should light the meter panel lamps in the Exciter Unit.

4. Close "CONTROL CIRCUIT BREAKER", Item 955, located on the fuse panel in the lower compartment of the Amplifier Unit. This applies power to the control circuit for the operation of contactors. If all doors are closed, the panel lamp "INTERLOCK ON" will light.

5. Close switch marked "TRANS. START", Item 440, on front panel of the Exciter Unit. This will close contactor, Item 458, and apply power to all tube filaments in the Exciter Unit. Adjust the auto-transformer until the line voltmeter, Item 419, indicates approximately 110 volts. The contactor, Item 458, will also operate contactor, Item 960, which will apply filament-heating power to the antenna monitor rectifier. Closing Item 440 also starts the time-delay relay, Item 421, which will withhold all plate voltage in the Exciter Unit for 30 seconds.

6. Close switch marked "COOLING UNIT", Item 965, located on the front panel of the amplifier. This will operate contactor, Item 933, which, in turn, will apply power to the pump motor. This operation will light the lamp marked "COOLING UNIT ON", located on the panel of the Amplifier Unit. After the water flow has reached the required minimum, the water flow interlocks, Items 967 and 968 will close and the lamp marked "WATER FLOW" will light.

7. Close circuit breaker, Item 935, located on the fuse panel in the lower compartment of the Amplifier Unit. This brings the filament power source up to the contactors.

8. Operate switch marked "FILAMENT VOLTAGE", Item 966, on the panel of the Amplifier Unit. This will operate contactor, Item 937, which will apply power to the UV-863 filaments through the line resistors, Item 938. After five seconds, the time-delay relay, Item 936, should close and operate the contactor, Item 939, which will short the line resistors and apply full voltage to the filaments. No plate power can be applied until Item 939 is in operation. The completed operation is indicated by a light marked "FILAMENT ON".

9. Close the circuit breaker, Item 1119, marked "RECTIFIER FIL"., located in the center of the Rectifier Unit's front panel. Since the contactor, Item 1121, for this circuit has already been closed by operating the switch "TRANS. START" on the Exciter Unit, the filaments of the rectifier tubes should light. The time-delay relay, Item 1151, will start operating and will prevent the plate power from being applied for 30 seconds. The lamp marked "FILA-

MENT" on the panel of the Rectifier Unit will light.

10. Operate the switch, Item 438, marked "PLATE VOLTAGE" on the panel of the Exciter Unit. This will close contactor, Item 457, provided the time-delay relay, Item 421, has closed. Other contacts on Item 457 will allow the completion of the plate supply circuit to the Amplifier Unit as soon as additional controls are operated. The lamp marked "PLATE ON", located on the Exciter Unit panel, will light.

11. Close circuit breaker, Item 1103, marked "PLATE VOLTAGE" on the panel of the Rectifier Unit. This brings the power source up to the contactors in this circuit.

12. There are two start switches; one, Item 1177, is located on the panel of the Rectifier Unit, and the other, Item 983, on the Amplifier Unit. The operation of either of these switches will close contactor, Item 1104, and apply power to the primary of the plate transformer through line starting resistors, Item 1106. Contactor, Item 1104, is equipped with time-delay contacts, which close approximately 5 seconds after the line contacts. These time-delay contacts operate contactor, Item 1105, and short the starting resistors. This operation completes the starting sequence as all plate and filament transformers are now being energized.

Completion of this operation will turn on the lamp "RECTIFIER ON", located on the panel of the Amplifier Unit and the "HIGH VOLTAGE" lamps, "SUPPLY" and "OUTPUT" on the panel of the Rectifier Unit. All the lamps, except the "OVERLOAD", should now be illuminated. The crystal oven lamp will light intermittently.

13. To stop the transmitter, the "TRANS. START" switch, Item 440, may be thrown to the "Off" position. This will close down the entire transmitter, with the exception of the water pump, which will run for a few minutes until the time-delay relay, Item 961, operates.

14. To remove plate voltage from the Amplifier and Rectifier Units only: Operate the "RECTIFIER STOP" switch, Item 984, on the panel of the Amplifier Unit, or the "STOP" switch, Item 1176, on the panel of the rectifier Unit. The operation of either of these switches will release contactor, Item 1104, and remove only the plate voltage on the Amplifier Unit.

15. To remove all plate voltages in the transmitter: Throw the "PLATE VOLTAGE" switch, Item 438, on the panel of the Exciter Unit to the "OFF" position. This will release contactor, Item 457, removing all plate voltages in the Exciter Unit (except the oscillator) and releases contactor, Item 1104, removing plate voltage from the Amplifier and Rectifier Units. The filament and water pump are not affected by this operation.

16. To remove the three-phase power supply to the transmitter, throw the circuit breaker, Item 1101, marked "LINE", on the panel of the Rectifier Unit. This removes all power except the 110-volt supply to the oscillator filament transformer and crystal oven heater. This 110-volt supply should never be disconnected unless it is necessary to work directly on apparatus in these circuits.

17. The water pump may be stopped at any time by opening the "COOLING UNIT" switch, Item 965, on the panel of the Amplifier Unit.

However, this should never be done unless absolutely necessary, as the tubes should be cooled for several minutes after the transmitter has been shut down. Failure to allow time for cooling may cause steam to form in the tube sockets. Should the switch, Item 965, be opened while the transmitter is on, all power is automatically removed from the Amplifier Unit.

18. If the transmitter is to be off for several hours, it will be advisable to throw the "LINE" switch, Item 1101, on the panel of the Rectifier Unit to the open position. However, this should not be done until the water pump has been stopped by the time-delay relay.

(c) Manual Operation. Routine manual operation will follow the above sequence, however, only those switches located on the front panels need be thrown. The "RESET" switch on the panel of the Rectifier Unit will be in the "MANUAL" position.

Usual practice will be to start by throwing the "LINE" switch on the rectifier unit panel. The "PLATE VOLTAGE" and "FILAMENT" switches will be left on at all times. The "TRANS. START" switch on the Exciter Unit will be thrown, and this will be followed by operating the "COOLING UNIT" and "FILAMENT" switches on the Amplifier Unit. After allowing sufficient time for the closing of the time-delay relays, the "PLATE VOLTAGE" switch on the Exciter Unit will be thrown, and this will be immediately followed by operating the "RECTIFIER START" switch on the Amplifier Unit.

Removal of power may be accomplished by reversing the above order or by operating the "PLATE VOLTAGE" and "TRANS. START" switches on the Exciter Unit. Do not throw the "LINE" switch until the water pump has ceased operation. The overload relay will automatically reset when the transmitter is again turned on after an overload.

(d) Automatic Operation. For automatic operation of the control circuits, the "RESET" switch, Item 1178, is thrown to the "AUTOMATIC" position. The sequence of operation is similar to that given above, if all switches have previously been turned on.

All filament voltages will be controlled by the operation of the "TRANS. START" switch, Item 440, on the panel of the Exciter Unit. All plate voltages will be controlled with proper time-delay by the operation of the "PLATE VOLTAGE" switch, Item 438, on the Exciter Unit. Item 438 may be thrown to the "ON" position before the "TRANS. ON" switch is operated, in which case the entire transmitter may be controlled from the "TRANS. START" switch.

If desirable, all switches up to the "RECTIFIER START" may be operated manually, and after they have been closed properly, the plate voltage to the Amplifier and Rectifier Units will automatically be applied after the proper time delay.

The advantage of the "AUTOMATIC" setting is that should any of the overload relays operate while the transmitter is in operation, the ratchet relay, Item 985, will allow the plate voltage to be re-applied twice, and if the overload continues, will then remain open, releasing relay, Item 457, and remove all plate voltages.

The operation of the ratchet relay is indicated by the red light, Item 986, marked "OVERLOAD" on the panel of the Amplifi Unit.

Before continuing operation, the ratchet relay, Item 985, wi have to be reset. Resetting is accomplished by throwing the "F SET" switch to the "MANUAL" position after the "TRANS. START" swit has been turned "ON". The "RESET" switch may then be returned the "AUTOMATIC" position.

6. WATER-COOLING SYSTEM

(A) GENERAL. A closed circuit water-cooling system is su plied with the transmitter. The system consists of a circulati pump, radiator and blower assembly and a copper supply tank. T assembly is so arranged that one three-phase, 220-volt inducti motor is used to drive both pump and blower.

This equipment is necessary to circulate and cool the wat used to dissipate the heat developed on the plates of the UV-8 vacuum tubes. The cooling capacity of the radiator is conserv tively rated at 25 KW continuously for ambient temperature not e ceeding 115 degrees F.

The use of distilled water is recommended, since water of hi mineral content causes a scale formation on the anodes of the tube A large copper supply tank is furnished and copper pipe and fi tings should be used for the installation. Approximately 60 ga lons of water are required to fill the system. It is filled at t tank; water being added until the water level is about half-way on the glass gauge.

The water-cooling assembly should be located in the basem or some other room other than the one in which the transmitter located. In any case, both the tank and pump assembly must be b low the level of the tube sockets in the transmitter. If they a not, it will be impossible to remove either of the 863 tubes wit out losing water. An advantage of locating the cooling asseml and tank below the transmitter level is that, when off the air, a the water in the system drains into the tank. In cold climat this prevents freezing in the tube sockets, porcelain water coi and piping.

The water pump is of the centrifugal type, with a capacity 20 gallons per minute when working against pressure of from 30 50 feet. The pump is driven at a speed of 1,750 r.p.m. by a 22 volt, 3 h.p. three-phase motor. The motor is of the "line sta induction type.

The general assembly and piping is shown in Fig. 12.

(B) PROTECTIVE DEVICES.

(a) Water Flow Interlocks. The exhaust water line for ea Radiotron UV-863 is equipped with a water flow interlock, Items 9 and 968, with electrical contacts for circuit connections. T interlock is actuated by the pressure caused by water flow throu the tube jacket. If the pressure is too low, the interlock remai in the "open" position, and it is not possible for any power to applied to the tube. Much depends on the operation of the wat interlocks, because the burning of the filaments alone without go

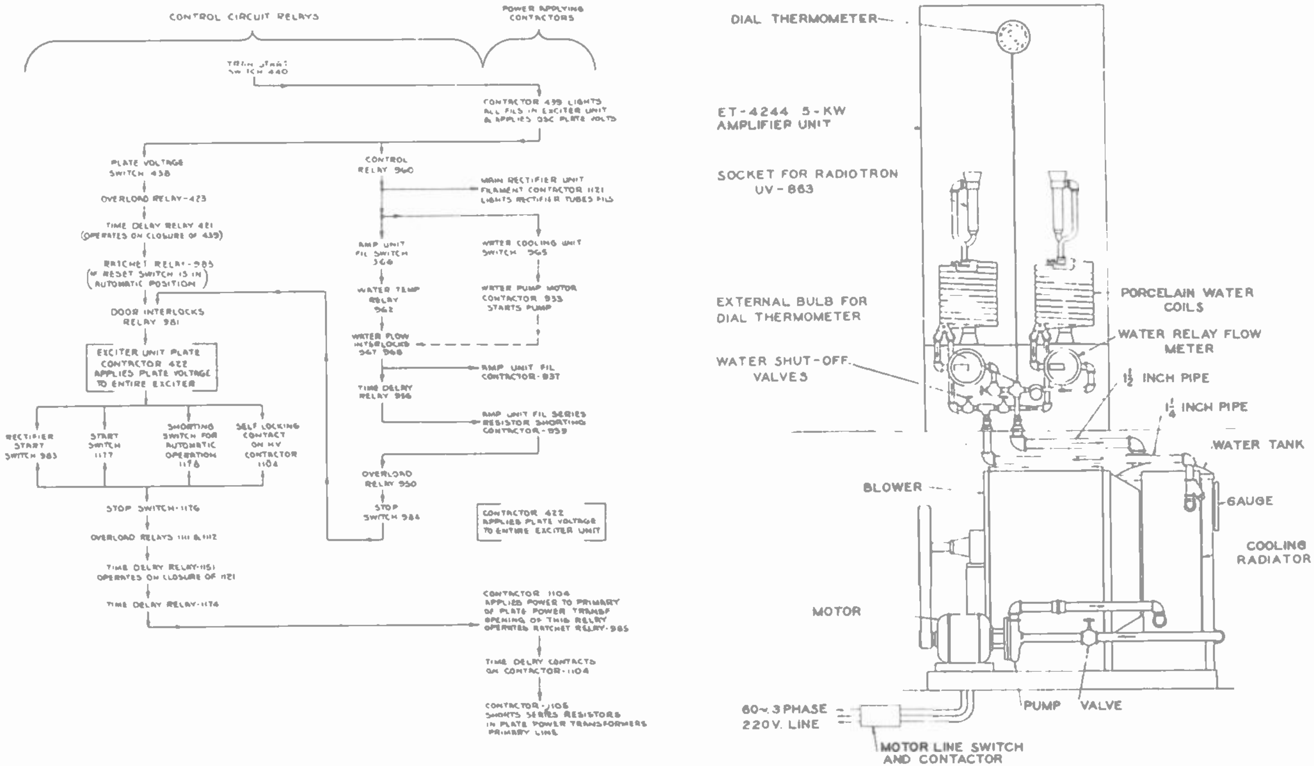


Fig.12 (A) Functional diagram for control circuits of 5-C Transmitter. (B) Diagram of water cooling system in 5-C Transmitter.

circulation of cooling water will damage a water-cooled tube in a short time. Failure of water when the tube is working at full load will destroy it in a few seconds. The water interlocks are positive and rapid in their functions, and are so connected that all power is removed from the water-cooled tubes when they open. Shut down, due to water failure on any tube, should be fully investigated, before applying power to the transmitter again. The water flow interlocks indicate directly the flow in gallons per minute. They are located at the rear of the 5 KW Amplifier. These interlocks should be set to operate at four gallons per minute. A water flow of five gallons per minute is usually required for each tube.

In running down water troubles, inspection should begin at the pump, unless the true cause is apparent. With the pump operating, and all valves open, water failure is due to a stoppage, break, or major leak. When looking for troubles, first refer to the pilot lights on the panels for guidance.

(b) Water Temperature Indicator and Interlock. Abnormal heating of one or both tubes, or the circulation of too hot water, is also dangerous to water-cooled tubes. The maximum safe temperature for exhaust water is 160 degrees F. Above this heat, the formation of steam bubbles near the tube anodes cause an abrupt rise in temperature because of inefficient transfer of heat to the water. The circulation of water for each Radiotron UV-863 will be approximately five gallons per minute.

The exhaust water from the two amplifier tubes passes over a thermometer bulb inserted in the pipe line, and this, in turn, actuates a dial-indicating thermometer, Item 963, mounted on the front of the panel, permitting the operator to observe the condition of the exhaust water at all times. Abnormal temperature rise, due to excessive dissipation in one tube only, is readily noticeable by an increase in the indicated temperature. All radio station log sheets, therefore, should include a periodic check of water temperature.

The thermometer is made to open an electrical contact to remove power from the transmitter when the temperature exceeds the maximum limit. The thermometer contacts are interlocked with the protective circuit and made to remove all power from the tubes. The practice is to set the thermometer contact permanently at maximum safe water temperature of 150 degrees F., allowing normal operating variations below this value to go as they will. Any troubles which would cause excessive heating would be more readily indicated by the other meters on the amplifier, or the power may be shut off directly by the overload relays.

(c) Water Leakage Meter. It is important that the water used in the cooling system offer as high a resistance as possible to the flow of current. This is necessary, because the plate of the UV-863 operates at a potential of approximately 14,000 volts and an appreciable current would flow to ground through the water stream if the conductivity were too great. A long, insulated water column is provided by inserting coiled porcelain pipes between the tube socket and the remainder of the water system.

A leakage current meter, Item 977, is located on the front panel of the amplifier and is connected across a lower section of the insulated water stream. Any current leakage through the water will develop a voltage drop across the section connected to the leakage meter, and will cause a deflection of the meter. If the reading of the water leakage meter exceeds 0.8 milliamperes, all the water should be drained from the system and replaced with clean, distilled water.

(C) CONNECTIONS. The resistance to the flow of water to and from the water coils and cooling unit should be kept as low as possible. Two-inch pipe is recommended for this. All water coils are to be connected in parallel in the water system. Water coil connections at the bottom of the coils lock down, which means that external connections will have to come up under the modulator and amplifier units in a vertical position. Care should be exercised that all connections are assembled to avoid possible leaks at present or future dates.

7. ADJUSTMENT OF APPARATUS. The various power voltages in the 5-C Broadcast Transmitter are held constant by the automatic line-voltage regulator, Item 1120. Adjustments of the filament power circuits in the AA-4424 5 KW Amplifier are made by varying taps on the filament filter resistors, which are located in the AP-4242 Rectifier Unit. The rectifier filament transformers have primary taps which may be adjusted for the normal line voltage. Readings may be taken of the line voltages by the "Line Voltmeter". Item 1116, which is connected to each of the three phases by its selector switch, Item 1117. Correct operation of the automatic line-voltage regulator is indicated by correct readings of the "Line Voltmeter". The line current to the plate power transformer is indicated by the "Line Current Meter", Item 1114, which is also controlled by a selector switch, Item 1115.

While the voltages in the ET-4241 Exciter Unit are also held to a constant value by the automatic line-voltage regulator, several variable controls are provided in various circuits throughout the unit. The following is a procedure which should be used in checking filament and bias voltages.

Byfore applying power to the equipment, a careful inspection should be made to assure that there are no loose connections, and all relays and contactors should be inspected to ascertain if they are in the proper mechanical order. The voltage control switch, located on extreme left side of the control panel, should be set to position No. 1, and resistors, Items 232, 266, 310, 317, 319, 441, 442, 1180, 1181 and 1182, should be set for maximum value. All power switches should be in the "OFF" position and no tubes should be placed in the transmitter.

Do not insert fuses in the plate rectifier supply line.

After closing the "Main Line Switch", Item 1101, on the rectifier panel, close the line switch, Item 416, located on the lower right fuse panel. Operate the switch marked "Transmitter Start", Item 440, and adjust the line-voltage switch, Item 449, until the line voltmeter, Item 419, indicates approximately 110 volts. an AC voltmeter, having an appropriate scale, should be connected across the filament terminals of one of the audio tube sockets, Item 307, and the variable resistor, Item 461, adjusted until the voltmeter indicates 10 volts. After the tubes have been inserted in the proper sockets, recheck the filament voltages.

The filament voltage at the terminals of all the sockets should be checked as indicated in the following table:

Crystal oscillator, RCA-843 tube, 2.5 volts ±5%.
Buffer amplifier, RCA-865 tube, 7.5 volts ±5%.
Intermediate amplifier, RCA-203A tube, 10 volts ±5%.
Modulated amplifier, RCA-203A tubes, 10 volts ±5%.
First audio amplifier, RCA-203A tubes, 10 volts ±5%.
Plate rectifier, RCA-872A tubes, 5.0 volts ±5%.
Power amplifier, RCA-863 tubes, 20.5 volts.

Adjust the resistance, Item 442, in the primary of the transformer, Item 411, to regulate the voltage across the field of the loudspeaker. The voltage should be between 5 and 8 volts and the field current 0.5 to 0.8 ampere.

(A) TUNING AND NEUTRALIZING ADJUSTMENTS. WARNING: NO ATTEMPT SHOULD BE MADE TO ADJUST OR OPERATE THE TRANSMITTER WITHOUT THE PROTECTIVE BACK AND SIDE SHIELDS IN PLACE. ALL VOLTAGES SHOULD BE REMOVED FROM THE TRANSMITTER BY THE PROPER CONTACT SWITCHES.

(a) General. Resonance is indicated in all radio frequency circuits, except the antenna, by an adjustment for minimum plate current of the tube whose tank circuit is being tuned.

When making neutralization adjustments, the plate voltage clips must be disconnected from the tank coils of the amplifier stage on which adjustments are being made and on all following stages. The purpose of this is to remove the plate voltage from these stages to permit neutralizing and to prevent damage to equipment.

For preliminary adjustments on the ET-4241 Exciter Unit, refer to previous information in this lesson.

(b) The 5 KW Power Amplifier. Make sure the high-voltage disconnect switch, Item 993, is open.

Two methods of operation are given for this amplifier. The first method provides for a power rating of the transmitter by measuring the power input to the final stage. When using this method, the input to the final amplifier is set at 15 KW, as given in equation (1), and adjustments made for the lowest possible audio frequency distortion consistent with 5 KW output.

$$(1) \quad W_{in} = E_p \times I_p$$

Where: W_{in} = Power input in watts.
E_p = Plate voltage of linear amplifier as shown on meter, Item 1125.
I_p = Total plate current in amperes of linear amplifier tubes as shown on Item 991.

The second method utilizes power output measurements based on antenna current and resistance readings as given in equation (2).

The antenna current is held at the value required for a 5 KW output and the circuit adjustments and power input varied for low audio frequency distortion. This latter method is to be preferred, because the operation of the transmitter is then in accordance with rigid requirements for high fidelity.

$$(2) \quad W_{out} = I^2_A \times R_A$$

Where: W_{out} = Antenna power in watts,
I_A = Antenna current in amperes,
R_A = Antenna resistance in ohms at the operating frequency.

The main difference between the two adjustments is in their respective amplifier efficiencies. The first method operates at a rather high efficiency (33%), while the second method operates at an efficiency of approximately 25%. Adjustments can, of course, be made which will give efficiencies which fall between those of the above two limits, but the station engineer is cautioned that any deviation from the second method of operation will result in less than maximum fidelity.

In a "Class B" Linear Amplifier, the output varies directly as the square of the radio frequency exciting voltage. The criterion of proper amplifier adjustment is low distortion which will, in general, depend upon efficiency at which the amplifier is operating. Any change in bias, r-f excitation, or plate loading will cause a change in amplifier efficiency. The proper value of bias resistors will depend to some extent upon the particular installation. The best adjustment from a low-distortion viewpoint will be found to be one that uses a comparatively low bias voltage, i.e., approximately 150 volts. Such a potential may be obtained with four paralleled 650-ohm resistors in the cathode circuit of each tube. Additional resistors are provided for close adjustment.

When using the 15 KW input method of power measurements, the best results will be obtained with approximately 200 volts bias. Three 650-ohm resistors in the cathode circuit of each tube will approximate the correct condition.

The presence of two independent variables, grid excitation and plate loading, makes the adjustment of a linear amplifier difficult. The "half - voltage" method makes the plate loading adjustments an independent operation, thus simplifying the tuning of the amplifier. The proper amount of coupling to the antenna is hard to determine in an under-excited amplifier, such as in the case of a "Class B" r-f amplifier. The r-f voltage across the plate tank circuit varies greatly with loading, optimum coupling is difficult to find, and double-humped tuning sets in.

With half-plate voltage, the available excitation is usually sufficient to saturate the grids of the tubes in the amplifier. Therefore, at half-plate voltage the amplifier is operating "Class C" and provides a voltage source with good regulation, which can easily be coupled to its load.

The four 650-ohm bias resistors are inserted for each tube, and the load coupling adjusted for the expected operating plate current determined from a knowledge of amplifier efficiency and plate voltage. At half-plate voltage, this efficiency is twice normal, so that when full voltage is applied to the plates, no great change occurs in the plate current. Notice that with the same plate current, the bias voltage will remain constant.

After the plate tuning and loading has been determined, the next step is to find the proper grid-exciting voltage. After full-plate voltage has been applied to the amplifier, the r-f exciting voltage will usually be too high. This voltage may be reduced by lowering the plate voltage on the modulated amplifier. Adjustments should be made in the final amplifier's grid-loading resistors to keep the modulated amplifier's plate current and voltage within the values given in the meter readings table while providing proper grid excitation for the final amplifier.

For preliminary adjustments, disconnect the r-f transmission line clips from the secondary of the plate tank coil, Item 930, and open the high-voltage disconnecting switch, Item 993.

Connect a thermo-galvanometer to a loop of wire having several turns and loosely couple to the plate tank coil, Item 930. The neutralizing capacitors should be disconnected. Variometer, Item 927, is adjusted for tank circuit resonance, as indicated by maximum reading on the thermo-galvanometer. Coarse adjustments are made by varying the taps on the tank inductance, Item 930, taking care to have the same number of turns in each section to preserve the balanced circuit arrangement.

The correct values of tank capacitors, Items 918 to 925, vary with the operating frequency.

The rotor of the variometer, Item 927, should tune the tank circuit to resonance when at an approximate 90-degree angle with the stator coil. Failure to tune at this angle can be corrected by varying the taps on the tank coils, Item 930.

Connect line switch, Item 1160, located in the Rectifier Unit on tap No. ¼, so that one-fourth normal plate voltage will be applied on the UV-863 tubes. Close the disconnect switch, Item 993, connect the neutralizing capacitors, and tune the tank circuit for minimum plate current. The plate current meters, Items 947 and 946, will read approximately the same values for correct balance. The plate voltage may be kept at the low value until all tuning on the transmission line and antenna circuits has been completed. Exact neutralization is not necessary and is almost impossible to obtain in high-power amplifiers. After normal plate voltage has been applied and the tubes are drawing normal plate current, measurements of bias voltage can be taken by connecting a high-resistance voltmeter across the bias resistor by-pass capacitors, Items 9421 and 9422. The bias voltage may be calculated by multiplying the plate current of each tube by the value of bias resistor used for that tube.

After the filament, plate, and bias potentials are adjusted to the correct operating value, the plate tank circuit tuned to resonance, and the outgoing transmission line properly terminated, the excitation voltage is controlled by changing the plate voltage on the second r-f amplifier.

Correct operation is judged by calculating the amplifier efficiency as follows:

$$\%Efficiency = \frac{Power\ Output}{Power\ Input} = \frac{I^2A \times RA}{Ip \times Ep}$$

Where: IA = Antenna current,
RA = Antenna resistance,
Ip = Total plate current,
Ep = Plate voltage of linear amplifier.

No efficiency greater than 33⅓% should ever be used, and as stated elsewhere, efficiencies which approximate 25% are strongly recommended.

All adjustments should first be made for 5 KW operation. For 1 KW, the plate voltage in the final amplifier is reduced to one-half normal. Simultaneously, the plate voltage on the modulated amplifier is reduced to a value which produces the proper r-f grid excitation for the final amplifier. No change is made in the bias or grid-loading resistors in the final amplifier.

When the power change relay, Item 9111, is in the 1 KW position, the modulated plate series resistor, Item 327, is varied until the final amplifier is delivering 1 KW output. Additional contacts on Item 9111 connect a resistor across the output of the modulator. This is done to keep the same load on the modulator for either power output. The audio input level will remain substantially the same.

After all adjustments have once been made, the power output of the transmitter may be changed by operating the power change switch, Item 9110. No other adjustments should be necessary.

The power change switch has an interlocking feature which removes all plate voltage from the transmitter while the contactors are being operated. Quick operation of this switch will make the operation of the power change equipment inaudible to the listener.

(B) ADJUSTMENT OF MONITORING EQUIPMENT.

(a) Loudspeaker. The volume of the loudspeaker is controlled by a potentiometer, Item 254, which is operated from the front panel of the Exciter Unit. Sufficient power is delivered by the rectifier to drive the speaker directly without the aid of audio amplifiers.

(b) Antenna Ammeter. The antenna ammeter, Item 243, located on the meter panel of the Exciter Unit, is adjusted to read the same as the thermo-couple antenna ammeter, Item 1008, which is located in the antenna tuning house. The adjustment is made by varying the r-f input to the antenna monitor and adjusting the shunting resistor.

(c) Modulation Meter. The modulation meter, Item 253, is located on the meter panel of the Exciter Unit) This meter is adjusted by varying its series resistor, Item 266, which is mounted on the resistor rack in the lower compartment of Exciter Unit. The

meter should be adjusted to read 100% when the cathode-ray modulation indicator is showing a completely modulated wave.

(C) TABLE OF TYPICAL METER READINGS - 5 KW CARRIER UNMODULATED

AMPLIFIER UNIT	5 KW OPERATION	1 KW OPERATION
Left and right plate current		
Indirect power measurement	.65 Ampere	215 Amperes
Direct power measurement	.75 Ampere	.35 Ampere
Total Plate Current:		
Indirect power measurement	1.30 Amperes	.43 Ampere
Direct power measurement	1.50 Amperes	.70 Ampere
Filament voltmeter	205 Volts	205 Volts
Water leakage meter	0.8 ma. max.	.4 Ma.
Water temperature meter	150° F. max.	150° F. max.
Tank current	5-10 Amperes	2-5 Amperes

RECTIFIER UNIT	5 KW OPERATION	1 KW OPERATION
Output Voltage:		
Indirect power measurement	12,000 Volts	7,000 Volts
Direct power measurement	13,400 Volts	7,000 Volts
Output Current:		
Indirect power measurement	1.30 Amperes	.43 Ampere
Direct power measurement	1.50 Amperes	.70 Ampere
Line voltage	220 Volts	220 Volts
Line current	60 Amperes	15 Amperes

EXCITER UNIT - TYPE ET-4241	
Line voltage (volts)	110
Oscillator plate voltage (volts)	250
Oscillator plate current (ma.)	10-20
Buffer amplifier plate current (ma.)	20-40
First r-f amplifier plate current (ma.)	50-100
Second r-f amplifier (indirect measurement of output)	200-300
Total plate current (direct measurement of output) (ma.)	——
Second r-f amplifier total grid current (ma.)	100-120
Second r-f amplifier tank current (amp. r-f)	.5-2.0
Second r-f amplifier plate voltage (volts)	900-1000
First audio amplifier total plate current (ma.)	45-55
Second audio amplifier (left)	75-100
Plate current (ma.) (right)	75-100

8. MAINTENANCE AND OPERATION

(A) General. The 5-C Broadcast Transmitter is designed and constructed to operate with a minimum of lost time from equipment trouble. However, it behooves the station engineer to have a regular inspection and maintenance schedule so that, if possible, future troubles can be anticipated and avoided.

Before transmitting, the transmitter should be started for a preliminary "warming" period; however, when time does not permit, the station can be put directly on the air. The recommended procedure would be for manual operation during the "warming-up" process and automatic operation while the transmitter is on the air.

The adjustments, water flow, and meter readings of the transmitter should be checked prior to each broadcasting period to insure proper operation. The operation of both crystals should be checked.

The frequency deviation and operating power must be measured and recorded at certain intervals as required by law. It is recommended that log records be made of all meter readings. Such a procedure will give a complete record of tube operation and circuit adjustment.

It is of importance that the transmitter be kept free of dust. Variable capacitors should be cleaned with an air blast. Isolantite insulators should be wiped with a dry cloth. A small blower may be used to clean out inaccessible parts. The meter panels may be cleaned by removing the meter panel light support and inserting a cloth-covered stick through the opening. The entire transmitter should be inspected periodically for loosened and broken connections. Clean and tighten all tank coil clips and connections. The jaws and blades of the tap changing and line switches should be lightly coated with vaseline. All fuses and fuse clips should be kept clean and bright. The contact tips of all contactors and relays should be kept smooth and clean and the mechanism checked for smoothness of operation.

Keep the bearings of the motors of the induction voltage regulator and the water pump motor properly lubricated. When cleaning apparatus, throw the main transmitter disconnecting switch, Item 1101, and make sure the filter discharge switch, Item 1127, has closed. All indicating lamps should be dark.

Occasional checks should be made of the bias resistors, by-pass capacitors, and fuses.

(B) Vacuum Tubes. It is recommended that regular checks be made to ascertain the condition of all tubes in the transmitter. Vacuum tubes should be removed when the filament emission begins to decrease as indicated by a decrease in plate current. Failure to obtain peak output during modulation, when all circuits are properly tuned, may indicate a defective linear amplifier tube. Repeated operations of arc-back indicators are caused by defective rectifier tubes. Audio distortion and plate current unbalance in the push-pull audio stages may be the result of an unsatisfactory audio amplifier tube.

When changing vacuum tubes in any part of the set, a record should be kept of the serial number and period of service. Actual hours of service can be measured on the filament hour meter. All tubes should be removed periodically and the tube prongs and sockets cleaned.

Spare rectifier tubes should be given a 15 minutes heat run before being placed on the shelf or rack. Always keep the tubes in an upright position and avoid splashing the mercury. If tube has been shaken or tipped, it should be again heated for 15 minutes before being placed in service.

Vacuum tubes of all types used in the transmitter should be mounted in a rack in a handy but safe location, so as to be instantly available in case of need. For replacement of any air-cooled tube, the set need not be off the air more than a few seconds. The time of shut-down required for changing a water-cooled UV-863 depends, to a large extent, on the skill of the operator. Where possible, all new operators should be trained in changing tubes at a time when the station is not in operation.

(C) CARE OF WATER-COOLED TUBES

(a) Unpacking. Each tube is shipped in a separate crate designed especially for the tube. No other method of shipment is used. The tube is suspended in the crate by tacking in a vertical position, with the cathode end up in such a way that minimum vibration is transmitted to the tube.

After unpacking and testing, the spares should be stored in racks built for this purpose. Tubes stored promiscuously are always in danger of being broken.

Do not expose the tubes to the weather.

Handle the crated tube and the tube itself with the same consideration as any piece of expensive glassware.

(b) Testing of Tubes When Received By Customer. Each Radiotron, before shipment, has been properly tested in the factory as to its electrical characteristics. Overload tests are made under actual operating conditions to insure its operation at normal voltage. The mechanical features of the Radiotron are carefully inspected to insure against any defect which will make it unfit for use. Overall dimensions are checked to see that they lie within certain predetermined limits, making the tube interchangeable with other tubes in the same mounting.

It is, therefore, advisable upon receipt and after unpacking of a Radiotron to carefully examine it to see that it has suffered no damage in shipment. Shake the tube slightly to see if any interior parts have become broken and are loose in the bulb.

(c) Notes on Operation of the Water-cooled Tubes. Be careful to make the filament connectors very tight, so as to prevent heating and possible destruction of the filament leads.

Before using the tube, note whether any foreign matter has fallen into the stem opening and lodged between the glass and the filament leads. The filament leads operate at a fairly high temperature, so that any shavings, paper or excelsior which might have fallen into the stem would become charred and possibly cause a puncture at this point. A blast of air will remove any light material.

Considerable care must be taken in fastening the grid lead connection of the tube so as not to strain the glass by causing the lead to become too tight.

Tube should be securely fastened in the water jacket and the fastening devices, which fit over the anode flange, tightened before any adjustment of grid lead is made. The water jacket should never be moved nor should the tightening devices on the anode flange be readjusted while the grid is connected to the set, as undue strain may very easily be put on the grid seal at such times.

The lead itself should never be so tight that any vibration or shock will cause tension on the lead, and it is especially desirable to avoid any tension in the plane at right angles to the grid lead where this lead leaves the glass seal.

Holes have been provided along the grid lead for use in short-wave installations where it is important to have short leads. Since the lead is made of soft, annealed copper, it is easily mutilated, and the connections should be made carefully.

In making connections, care must be taken that the wires are not so tight as to put a strain between the glass and anode.

In making connections, see that the wires do not lie on or close to the surface of the glass. Otherwise, serious trouble may arise from corona, and almost certain puncture.

At any time during the handling of the tube, be careful that the filament leads do not swing so as to strike the glass.

For gasket material, velumois, rubber-lead or lead may be used.

Do not use an adhesive to secure the gaskets against leaks. It is recommended that both the upper and lower surfaces of the anode flange and the other moving parts of the water jacket be covered with oil or oildage, preferably the latter. Wipe the surplus off, leaving a thin coating of oil, which will prevent the sticking of the retaining lugs or the flange to the water jacket and the rusting of the threads and levers.

Do not drop the tube into the water jacket.

After operating the tube and before turning off the water preparatory to removing the tube, be sure that the inner elements are below a red heat. In removing the tube, fold the levers back as far as possible. If this is not done, the tube will stick, and an attempt to force it may break the large plate seal. Never force the tube when removing it from jacket. Manipulate it carefully so as not to put large strains on the glass.

When these tubes are put into operation, after a period of rest, or when any changes or repairs have been made in the apparatus or circuit, it is strongly recommended that a lower value of plate voltage be employed. Very often some little change has occurred in the tube or equipment which would involve severe overload of the tube if operation were immediately begun on rated or normal voltage.

A singing or buzzing noise from the jacket while the tube is operating generally indicates the formation of air or steam bubbles at the surface of the anode. Thus operation above this temperature is not recommended. Increased water flow may, therefore, be necessary.

As heretofore stated, it is essential that scale formation be eliminated entirely. In emergency cases where the scale is formed, such as in a temporary shortage of water supply or during the modification of a cooling system which produces scale, it is recommended that a regular schedule for cleaning the scale on anodes be adopted. The frequency of cleaning will depend upon the rate at which the scale is formed. Obviously, the frequent removal of tubes from the jackets is objectionable, because of the danger of accidental breakage. Therefore, the only positive insurance against failure due to scale is the elimination of the scale entirely.

At all times during storage, transportation, handling and use, keep the tube in a vertical position, with the cathode end up.

During operation of an unusual nature, such as may be occasioned by surges, the elements of the tube may emit gas.

The safest way in which evolved gas may be cleaned up is by operation as a power amplifier or oscillator using reduced plate voltages.

It is especially desirable to avoid the sudden application of high plate voltage on a tube. Therefore, any clean-up method which involves such procedure should never be used.

(d) Life of Vacuum Tubes. One of the most important features of a vacuum tube is that its operation life shows a wide variation with respect to operating conditions, and to some extent with respect to individual tubes of the same type.

Tube failures fall into two general classes: (1) Normal or accelerated filament burn-outs. (2) Failures from causes other than filament burn-outs.

(D) CARE OF SMALL STATION-TYPE TRANSFORMERS.

(a) Handling. The transformer should be lifted by means of a sling and spreader attached to the eyebolts or lugs. This spreader should have a length equal to the distance between the lifting points. If rollers are used, skids should be put under the transformer to distribute the weight evenly over the base.

(b) Inspection. The transformer, and particularly the porcelain bushings, should be carefully inspected for evidence of damage incurred during shipment.

Small station-type transformers are usually shipped filled with oil. Such transformers are dried and filled with oil at the factory and may be installed immediately. However, before installing, the inside of the tank, particularly the underside of the cover, should be carefully inspected for evidence of damage incurred during shipment. Samples of oil should be taken from the top and bottom of the tank and tested. A transformer that shows signs of moisture, or has oil of a dielectric strength less than 22 kv., should be dried.

A transformer shipped without oil should be carefully inspected for evidence of moisture, and dried if moisture is detected. Dirt or dust on the cover or coils or on the inside of the tank should be washed away with dry oil under pressure. An inspection should also be made for parts which may have worked loose, such as leads and nuts.

(c) Gaskets. When making a gasketed joint, first see that the surfaces are thoroughly clean. Then dip the gasket in (or brush it all over with) varnish, preferably GE-428. Allow the varnish to set for several hours, then tighten the bolts evenly. To obtain the best results, the bolts should be re-tightened at intervals of three hours or more, until the gasket is compressed to about one-quarter its original thickness. All joints in gaskets should be scarffed for at least one inch, and stuck together. No sticker should be used on the gasket around the ratio adjuster shafts.

(d) Connection and Leads. Transformers are shipped connected for the highest voltage given on the nameplate, unless otherwise specified. No connections should be made, except those authorized on the nameplate or connection diagram.

Connections should not be changed on a transformer under excitation. When internal connections are changed, care should be taken to see that all joints are fastened securely, and that ratio adjusters are set properly. To change connections on a transformer with ratio adjuster, remove the adjuster cap and turn the handle until the indicator points to the desired position. On the "plunger" type, lift the shaft about 7 inches and then turn to the desired position, replace the cap and tighten it to exclude moisture.

NOTE: Never force an adjuster with a wrench.

Leads not in use should be carefully insulated from ground and all other leads.

When a transformer has flexible leads and these are connected to other leads or service lines, care should be taken to keep all such joints below the level of the transformer entrance bushing in order to lessen the possibility of moisture seeping along the wire, under the insulation, and into the transformer.

Permanently and effectively ground the transformer tank by means of the grounding lug or screw provided for this purpose near the bottom of the tank.

(e) Filling Transformer with Oil. Make certain that the transformer is filled with oil before applying voltage.

When it is necessary to fill the transformer with oil, make certain that both the transformer and the oil are free of moisture. The transformer should be filled to the proper "oil level" with the oil called for on the nameplate, and having a dielectric strength of 22 kv. or higher when tested between 1-inch discs spaced 0.1 inch apart. The oil temperature should be approximately 25 degrees C. to allow for expansion when the transformer is heated to normal temperature.

Whenever possible, the filling should take place in a clean and dry room, but if it must be done out of doors during damp or stormy weather, care should be exercised to keep moisture out of the transformer and oil. Rubber hose should never be used.

(f) Care of Transformer in Service. A transformer should be protected from excessive current or overloads and overvoltages due to lightning or surges, with suitable and approved protective devices properly located and connected. Refer to the nearest General Electric office for specific reccomendations.

The oil should be frequently inspected for oil level and dielectric strength. Oil that tests 16.5 kv. or less should be dried.

Oil that has deteriorated should be changed for clean, dry oil. Core, coils, and inside of tank should be carefully cleaned of all old oil, using clean, dry oil under pressure.

The top oil temperature for maximum-rated self-cooled transformers under continuous operation should not exceed 75 degrees C.

(g) General. Instructions on drying transformers, sampling, testing, and drying oil, recommendations for suitable protection, data on operation with other transformers, or any information desired relative to the operation of the transformer will be furnished upon request to the nearest office of the General Electric Company.

PARTS LIST

TYPE ET-4241 EXCITER

Schematic Item No.	Description
100	Crystal oscillator unit
118	RCA Type 129-B crystal holder
119	Crystal bypass resistor 2.2 megohms, 1 watt carbon type
120	Grid leak resistor, 100,000 ohms, 1 watt, carbon type
121	Series grid resistor, 47 ohms, ½ watt, carbon
122	Coupling capacitor, Faradon Model AF, .02 mfd., 700 volts
123	Tube socket, 5 prong
124	Tank inductance
125	Tank capacitor, Cardwell, 365 mfd.
126, 127	Bypass capacitor, Faradon Model AF, .02 mfd., 700 volts
128	Filament transformer, RCA Type XT-1208A
129	Transfer switch
130	RF choke
132	Vernier capacitor, Cardwell, 20 mmfd.
133	Tank capacitor, Cardwell 365 mmfd.
134	Tank inductance
135	Vernier capacitor, Cardwell, 20 mmfd.
136, 138	Bypass capacitor, Faradon Model AF, .02 mfd., 700 volts
139	Coupling capacitor, Faradon Model AF, .02 mfd., 700 volts
219	Blocking capacitor, .001 mfd., 5,000 volts, Model AF.
220	Neutralizing capacitor, Cardwell, 35 mmfd.
221	Buffer amplifier grid resistor, 15,000 ohms, 2 watts, wire wound
222	IPA grid resistor, 15,000 ohms, 10 watts, wire wound
223	Tube socket, RCA Type UT-541
225	Filament transformer, XT-1209
226	Bypass capacitor, .01 mfd., 2,000 volts, Faradon Model F.
227	RF choke
228	Plate inductance
229	Tank capacitor, refer to chart
230	Tank capacitor, refer to chart
231	RF choke
232	P. A. grid leak resistor, 5,000 ohms, 75 watts, adjustable
233	Tube socket, RCA Type UT-541
234	Capacitor, refer to chart
236	Thermo - couple, 0 to 5 amps., for for use with Item 237
237	P. A. tank ammeter, 0 to 5 amps.
240	Loading inductance
241	Capacitor, .001 mfd., Model UC-3073-K
243	Antenna ammeter
244	Antenna thermocouple, for use with Item 243
245	RF choke
246	Meter bypass capacitor, .01 mfd., Model RF, 700 volts
247	D-C milliammeter, 0 to 150 ma.
248	Meter bypass capacitor, same as 246
140	Series grid resistor, 47 ohms, ½ watt, carbon type
141	Grid leak resistor, 100,000 ohms, 1 watt, carbon type
142	Crystal bypass resistor 2.2 megohms, 1 watt, carbon type
143	RCA Type 129-B crystal holder
149	Tube socket, 5 prong
150	Coupling resistor, 10,000 ohms, 1 watt, carbon type
151	Bypass capacitor, Faradon Model AF, .02 mfd., 700 volts
152, 153	Thermostat capacitor, .0025 mfd., 700 volts, d-c
154	Heat resistor
155	Thermostat
156	Heat resistor (same as Item 154)
157	Thermostat (same as Item 155)
200	Radio frequency amplifiers
202	Coupling capacitor, .00004 mfd., 5,000 volts, Faradon Model F.
204, 5, 6	Bypass capacitor, .01 mfd., 2,000 volts, Faradon Model F.
208	Buffer amplifier tank capacitor, Cardwell, 500 mmfd. per section
209	Plate choke coil
218	Plate inductance

Schematic Item No.	Description
249	D-C milliammeter, 0 to 500 ma.
250	Meter switch
251	Meter switch
253	Modulation indicator meter, 0-1.5 ma.
254	Loudspeaker volume control potentiometer, 500 ohms
258, 259	Neutralizing capacitor, Cardwell, 35 mmfd.
262	Bypass capacitor, .01 mfd., 2,000 volts, Faradon Model F.
266	Modulation indicator adjusting resistor, 10,000 ohms, 75 watts
267	Filament transformer, XT-1548
271	Tube socket
272	Frequency monitor coupling capacitor, .0001 mfd., Faradon Model UC-3127, case 351
273	Tank capacitor, refer to chart
274	Buffer amplifier grid choke
275	Bypass capacitor, .01 mfd., Faradon Model F.
276	Resistor, 7,000 ohms tapped
277	Resistor, 8,000 ohms tapped
278	Tank capacitor, .00015 mfd., Faradon Model UC-3120, case 352
279	IPA grid choke
280	Bypass capacitor (same as Item 203)
282	Bypass capacitor (same as Item 203)
283	Bypass capacitor (same as Item 246)
284	Resistor, 50 ohms
285	Capacitor, 10 mfd.
287	Modulation meter connection switch
288	Bypass capacitor (same as Item 246)
289	Bypass capacitor, .01 mfd. Faradon Model, UC-3202, case 352
290	Loudspeaker assembly
291	Tank tuning capacitor
292	PA tank inductance
293	Antenna coupling coil integral with Item 292
294	PA grid resistors, 100 ohms, 10 watts
300	Audio frequency amplifier and modulator
301	Audio input transformer, XT-1584
302	Audio input load resistor, 100,000 ohms, 1 watt, carbon type
303	Tube socket
305	Interstage transformer, XT-1602
307	Modulator tube sockets, RCA Type UT-541
308	Modulator interstage transformer, XT-1690
312	Modulator reactor, XT-1190
316	Power change switch
317	Bias resistor, 750 ohms, 75 watts, variable
319	Resistor, 16,000 ohms tapped at 8,000 ohms, 200 watts
321	Grid resistor, 100,000 ohms, 1 watt
323	Grid resistor, 10,000 ohms, 1 watt, carbon type
327	Power change rheostat (tandem mounted), 2,250 ohms, 150 watts per unit
328	Resistor, 1,100 ohms, 200 watts
329	Resistor, 500 ohms, 200 watts tapped
330	Bypass capacitor, 5 mfd., 1,500 volts
331	Blocking capacitor, 2 mfd., 2,000 volts
332	Resistor, 220,000 ohms
333	Bypass capacitor, 5 mfd.
334	Resistor, 50 ohms, 10 watts
335	Resistor, 75 ohms, 20 watts
336	Resistor, 13,000 ohms
400	Power equipment
401	Fuses, cartridge type, 6 amps., 250 volts
402	D-C voltmeter, 0-500 volts
403	Capacitor (same as Item 246)
404	Potentiometer, 10,000 ohms, 50 watts
406	Filter reactor, UP-1653
407	Rectox rectifier units
408	Rectifier transformer, XT-1210
409	Filter reactor, Y-1289
410	Rectox rectifier units
411	Rectifier transformer, XT-1211
414	Auto transformer, XT-1212
415	Fuses, cartridge type, 30 amp., 250 volts
416	Line switch, 30 amp., 250 volts
417	Fuses, cartridge type, 10 amps., 250 volts
419	Filament voltmeter 150 volts a-c
421	Time delay relay, oil dashpot type
423	D-C overload relay
424	Door switch
426	Fuses, cartridge type, 20 amps., 250 volts
427	Plate transformer, XT-1213
428	Rectifier tube RCA Type, UT-541
429	Filament transformer, Y-2343
430, 31	Filter reactor, Y-2107
432	Filter reactor, XT-1198
435	Bypass capacitor (same as Item 246)
436	Plate voltmeter, 0-1,500 volts, d-c
438	Plate voltage switch
440	Transmitter start switch
441	Resistor, 5,000 ohms, 75 watts, adjustable
443	Crystal heater switch
445	Indicator lamp plate voltage, red
446	Indicator lamp crystal heater, green
448	Meter panel lamps, intermediate screw case, 115 volts, 15 watts
449	Line voltage switch
450	Multiplier for use with voltmeter, Item 436
452	Filter resistor, 500,000 ohms, 3 watts
454	Resistor, 50 ohms, 75 watts, adjustable
455	Modulator bias potentiometers, 300 ohms, 50 watts
456	Capacitor, 30 mfds., 330 volts, a-c
457	Plate contactor
458	Filament contactor
459	Bypass capacitor (same as Item 246)
460	Resistor, 15 ohms
461	Resistor, 15 ohms, adjustable
462	Filter capacitor, 20 mfd., 300 volts, a-c
463	Filter capacitor, 10 mfd., 1,500 volts, a-c
464	Filter capacitor, 2 mfd., 1,500 volts, a-c
465	Resistor, 80 ohms tapped
466	Filter capacitor, 30 mfd., 330 volts, a-c

TYPE AA-4244, 5 KW AMPLIFIER

Schematic Item No.	Description
901	Grid variable capacitor, 90 mmfds.
902–3	Grid fixed capacitor, case 99
904–5	Meter bypass capacitor, .01 mfd.
906–7	Neut. cap., 30-50 mmfd.
908–10	Fil. bypass cap., .05 mfd.
909–11	Tube socket
912	Tank ammeter: Square case Round case
913	Tank ammeter thermo-couple
914–5	Meter bypass capacitor, .01 mfd.
916	Plate parasitic choke, R. H.
917	Plate parasitic choke, L. H.
918–25	Plate tank capacitor, case 111
926	Plate bypass capacitor, .0005 mfd.
927	Plate tank variometer
928	Plate R. F. choke coil
929	Plate tank grounding resistor, 250 ohms
930	Plate tank and coupling coil
931–2	Meter bypass capacitor, .01 mfd.
933	Water pump motor starting contactor
934	Radiator and pump unit
935	Amplifier filament line switch
936	Amplifier filament delay relay
937	Amplifier filament starting contactor
938	Amplifier filament starting resistors, 32 ohms
939	Amplifier filament running contactor
940–1	Amplifier filament transformer, XT-1496
942–3	Bias filter capacitors, 28 mmfd.
944–5	Bias resistor, 650 ohms
946–7	Plate current ammeter: Square case Round case
948	Overload relay shunt resistor, 5 ohms
950	D-C overload relay
955	Control circuit line switch
957, 958, 959	Socket Bull's-eye (red) Bull's-eye (green) Lamp, 18 volts
960	Control system relay
961	Time delay relay for water system
962	Water temperature protective relay
963	Water temperature indicator
964	Resistor for water temperature relay, 2,200 ohms
965	Switch for water pump control
966	Switch for amplifier filament control
967–8	Water flow interlock and indicator
969–72	Door interlocks
973	Voltmeter switch for amplifier filament circuits
974	Amplifier filament voltmeter Square case Round case
975	Meter bypass capacitor, .01 mfd.
977	Water current leakage meter
978	Meter bypass capacitor, .01 mfd.
979	Resistor for leakage meter, 20 ohms
981	Relay for door interlocks
983	"Start" switch for rectifier
984	"Stop" switch for rectifier
985	Notching relay
986, 987, 988	Lamp, 18 volts Socket Bull's-eye, green Bull's-eye, red
989	Plate protection resistor, 32 ohms
990	Grid current milliammeter: Square case Round case
991	Total plate current ammeter: Square case Round case
992	Tube hour meter Square case Round case
993	High voltage disconnect switch
994	RF pickup coil
995	Grid bias RF choke coil
996	Lights for meter panel
997	Monitor filament fuses, 6 amp.
998-9	Grid load resistor, 10,000 ohms
9011	Grid spark gap
9061-71	Neut. cap., 28 mfd., UC-3220-K
9100	Grid grounding cap., .05 mfd., UC-2001 K
9101-02	Grid choke
9103	Heater strips for Item 933
9104-05	Bias bypass capacitors, 12 mfd.
9106-07	Bias capacitor fuses, 2 ampere
9108-09	Grid inductor
9110	Power change control switch
9111	Low voltage power charge relay
9112-13	Transmission line series capacitor
9115	Modulator meter power change relay
9161	Plate parasitic choke, R. H.
9171	Plate parasitic choke, L. H.
9261	Plate bypass cap., .003 mfd.
9281	Plate RF choke coil
9381–82	Amplifier filament starting resistor, 32 ohms
9401–02	Amplifier filament transformer, XT-2145
9411-12	Amplifier filament transformer XT-2145
9421–22	Bias filter capacitor, 25 mfd.
9441–42	Bias resistor, 1,300 ohms
9443–44	Bias resistor, 2,600 ohms
9445–46	Bias resistor, 8,400 ohms
9981–82	Grid load resistor, 4,000 ohms
9983–84	Grid load resistor, 6,400 ohms
9985–86	Grid load resistor, 10,000 ohms

Schematic Item No.	Description
	ANTENNA UNITS (Types AZ-4243 and AZ-4272)
1001–2	Line terminating capacitor, case 77
1003	Harmonic tank variometer
1004	Coupling transformer
1005	Antenna loading inductance
1006	Antenna series capacitor, case 77
1007	Static drain choke
1008	Antenna ammeter
1009–10	Line terminating capacitor, case 77
1011	Antenna series capacitor, case 77
1012	Antenna ammeter switch
1041	Static drain choke
1042	R. F. bypass capacitor, .01 mfd.
1043	R. F. bypass capacitor, .01 mfd.
1044	Antenna loading inductance
1045	Antenna series capacitor, case 111
1046	Antenna series capacitor, case 111
1047	Antenna load coil
1048	Antenna load capacitor, case 111

Schematic Item No.	Description
1049	Monitor pickup coil
1050	Antenna load capacitor, case 111
1051	Antenna load coil
	ANTENNA MONITOR UNIT
1013	Safety gap
1014–15	Monitor tube sockets, UT-541
1016	Filament transformers, XT-1547A
1017	Bypass capacitor, .001 mfd.
1018	Inductor, XT-1679
1019	Grounding capacitor, 4 mfd.
1020	Blocking capacitor, 4 mfd.
1021	Audio transformer, RT-123
1022	Compensating inductor, XT-1057-22A
1025	Resistor, 2,700 ohms, tapped
1026–27	Resistor, 1,250 ohms, tapped
1028	Resistor, 5,000 ohms, tapped
1029	Meter shunting resistor, 3 ohms
1030	R. F. choke coil

TYPE AP-4242 RECTIFIER

Schematic Item No.	Description
1101	Transmitter line switch
1103	Rectifier line switch
1104	Rectifier starting contactor
	Tips
1105	Rectifier running contactor
	Tips
1106	Rectifier step starting resistor, 5.5 ohms
1107, 1108	Lamp, 18 volts
	Socket
	Bull's-eye, red
	Bull's-eye, green
1109–10	Current transformer
1111–12	A-C overload relay
1114	Line ammeter
1115	Line ammeter switch
1116	Line voltmeter
1117	Line voltmeter switch
1118	Main rectifier transformer
1119	Rectifier filament line switch
1120	Voltage regulator
	Contact tips
1121	Rectifier filament contactor
1122	Rectifier filament transformer, XT-1511
1123	UV-872-A tube sockets, UT-541
1124	Arc back indicator
1125	Plate voltmeter
1126	Multiplier for plate voltmeter
1127	Horn spark gap
1128	D-C load ammeter
1129	Ammeter shunt resistor, 5 ohms
1130	Transformer for meter lamps, XT-1596
1131–33	Amplifier filament filter capacitor, 50 mfd.

Schematic Item No.	Description
1134–36	Amplifier filament filter capacitor, 15 mfd.
1137	Amplifier filament filter capacitor, 10 mfd.
1140	Amplifier filament filter capacitor, 25 mfd.
1143–45	Amplifier filament filter capacitor, 7 mfd.
1146, 1148	Lamp, 18 volts
	Socket
	Bull's-eye, red
	Bull's-eye, green
1150	Air blower motor
1151	Time delay relay
1152–7	Door interlock
1158	Filter reactor, XT-1512
1159	Filter capacitor, 2 mfd.
1160	Link switch assembly
1174	Short circuiting switch
1176	Rectifier "stop" switch
1177	Rectifier "start" switch
1178	Control switch "remote - automatic"
1179	Power change contactor
1180–82	Amplifier filament series resistor
1183–85	Amplifier filament filter reactor
	Lamp bulbs, indicating lights
	Lamp bulbs, meters
	Indicating lamp resistor
	Bearing for blower
	Belt for blower
	Packing for pump
	Packing gland for pump

The text of this lesson was compiled and edited by the following members of the staff:

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UNIT NO. 4

SPECIAL TRANSMITTER CIRCUITS

LESSON NO. 9

YOUR BANK BOOK OF LIFE

.....each day an entry is made.

The knowledge and experience that you accumulate day by day during your life may be compared to deposits of money that you make at your bank. Each deposit in your bank account increases your reserve of ready cash. And each deposit of knowledge that accumulates in your bank book of life increases your ability to earn money.

The daily accumulations in your bank book of life may not be large. But, taken over the period of a month or a year they will grow to substantial proportions. As time progresses, you will invest your accumulated knowledge in profitable employment. And your employer will pay you dividends on your investment in the form of wages.

Many people do not realize, that at the close of each day, an entry is made in their bank book of life. Consequently, the great majority of entries are simply zero, zero. And as time marches on, they will have nothing more to invest in profitable employment. The results being that the dividends they receive in the form of wages will remain stationary or even grow less with the passing of each year.

Fortunately, you know that the bank book of life actually exists. Day by day you are being credited with entries that employers are glad to pay good dividends for. And those entries are KNOWLEDGE.....something that no one can ever take away from you.

As the months and the years pass, you will accumulate additional knowledge so that you will continually have more and more to invest in profitable employment. Your reward will be constantly increasing dividends that YOU will receive in the form of wages. In other words, your cash income will grow with the years.

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Lesson Nine

SPECIAL TRANSMITTER CIRCUITS

"In this lesson you are going to find several subjects covered which will bring your commercial transmitter information up to date.

"Manufacturing companies are continually improving their products and it is not unusual for them to install some improvement on a transmitter even though it has been in service for some time.

"We are sure that you will find the information in this lesson quite helpful. However, if additional information is desired, the company from which the transmitter was originally purchased will be more than glad to cooperate in assisting you to secure the best in performance from the equipment."

1. THE DOHERTY HIGH-EFFICIENCY LINEAR AMPLIFIER. It is well known that the greatest disadvantage of the conventional Class B linear amplifier is its comparatively low efficiency. At the peaks of 100% modulation, the efficiency can easily be made 60% or better, but in ordinary speech and music these peaks are rare and the average percentage of modulation is nearer 60%. The linear amplifier is an efficiency-modulated circuit, in that its efficiency changes during modulation. The efficiency is roughly proportional to the RF voltage present across the tank circuit. When the grid excitation voltage is great enough to drive the tube up to its saturation point, the peak RF voltage across the tank is nearly 90% of the DC plate voltage and the stage is relatively efficient. As is well known, however, the stage cannot be operated under these conditions when unmodulated, for then the RF voltage across the tank would not be able to double its value during 100% modulation peaks. The peak of a 100% modulated wave is twice as great as the unmodulated carrier, and in order for the tank voltage to increase linearly with the grid excitation, it is necessary that the RF voltage across the tank, when the stage is unmodulated, be not more than half as large as the maximum possible. Thus, the efficiency of an unmodulated linear amplifier is approximately 30% and does not increase much above this value during ordinary modulation.

If it were possible to operate the amplifier tube under its most efficient condition even when the excitation voltage was unmodulated, the average efficiency of the circuit would be increased considerably. This problem has been satisfactorily solved by W. H. Doherty of the Bell Telephone Laboratories, and the result is the Doherty high-efficiency linear amplifier. Fundamentally, this new linear amplifier consists of two tubes, one of which is adjusted to give about 60% efficiency when the grid excitation is at the carrier level. The other tube is biased to approximately twice cutoff, and does not begin to function until the excitation voltage rises above the carrier level. Thus, the first tube operates efficiently at all values of grid excitation up to the carrier level and its output voltage is linear from zero grid excitation up to the carrier level, but beyond this point the linear

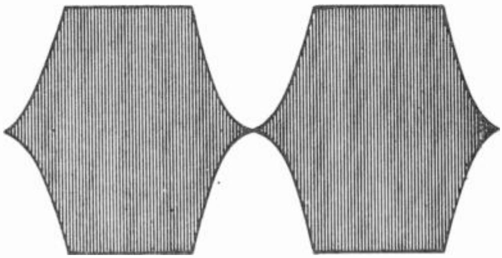


Fig.1 The output voltage of the carrier tube with 100% modulation.

relationship does not hold. This is due to the fact that with this amount of grid excitation the first tube becomes saturated and its output voltage can no longer increase.

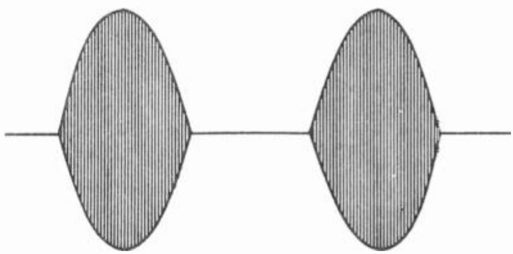
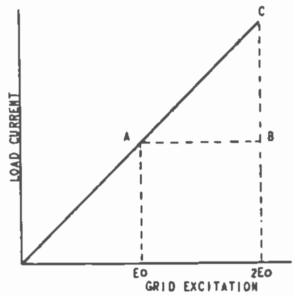


Fig.2 The output current of the peak tube with 100% modulation.

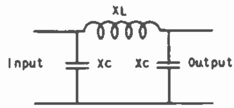
Now is the time that the second tube comes into play. It begins to furnish power to the load circuit, and in addition, it so changes the adjustment of the circuit that the first tube is able to increase further its power output without increasing its output voltage. The waveform of the output voltage of the first tube when the grid-exciting voltage is 100% modulated is shown in Fig. 1. Notice that the output voltage does increase uniformly from zero up to the carrier level, after which it flattens out and rises no further. In Fig. 2 there is illustrated the waveform of the current of the second tube. It is seen that no current flows through this tube until the excitation voltage rises above the carrier level. The relationship between the load current and the excitation voltage is illustrated in Fig. 3. In this figure E_0 represents the voltage at the carrier level, and $2E_0$ is the voltage at the peak of a 100% modulated wave.

Fig.3 The relationship between the load current and the grid excitation.



At the peak of the completely modulated wave, the first tube supplies twice as much power as it does at the carrier level, and, in addition, the second tube supplies an equal amount of power. Therefore, the total amount of power furnished to the load at the peak of modulation is four times as great as at the carrier level. Thus, in Fig. 3, the line AB indicates what the load current would be above the carrier level, if the second tube did not begin to function.

Fig.4 An impedance inverting network.



It is to be understood that the load impedance is so adjusted that the first tube is at the saturation point even when the excitation voltage is unmodulated. This means that the peak alternating plate voltage of this tube is nearly as great as the applied DC plate voltage. Now, the only way that this tube can furnish more power to the load without increasing the plate voltage swing is for the load into which this tube works to be reduced. The power furnished to a load is equal to the voltage across the load squared divided by the load impedance. If the load impedance be reduced, more power will be supplied to the load at the same voltage. This reduction of the load into which the first tube delivers its power is accomplished by an impedance inverting network.

An impedance inverting network is a circuit having four terminals, two input and two output. It has such a characteristic that the impedance measured across its input terminals is inversely proportional to the impedance measured at its output. Thus, whenever the impedance across the output is raised, that appearing across the input is correspondingly lowered, and vice versa. A circuit of this type is illustrated in Fig. 4. It consists of two condensers and one inductance. The inductive reactance of the coil is equal to the capacitive reactance of each of the two condensers at the carrier frequency. To prove that this circuit does invert the impedance, let us assume that its output terminals are open; that is, than an infinitely high impedance is connected across the output. With an infinite impedance across the output, the impedance measured at the input terminals should be zero. By redrawing the circuit as shown in Fig. 5, it is seen that the combination of the coil L and the condenser C2 form a series resonant circuit, and assuming that the resistance of the network is negligible, it is apparent that the impedance measured across the input is practically zero since a series resonant circuit has zero impedance.

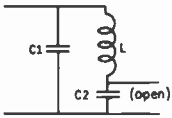


Fig.5 Illustrating that the input impedance is zero when the output terminals are open.

Now let us assume that the output terminals are shorted, or that zero impedance is present across the output. In this case the impedance measured at the input terminals should be infinitely high. When the output terminals are shorted, the condenser C2 is shorted out and the circuit appears as shown in Fig. 6. It is seen that the condenser C1 and the inductance L form a parallel resonant circuit across the input terminals. The shunt impedance of a parallel resonant circuit (neglecting the resistance which the circuit has) is infinitely high, and so the impedance measured across the input terminals is infinite.

The impedance measured at the input terminals is given by this formula:

$$R1 = \frac{X^2}{R2}$$

Where: R1 is the input impedance,
X is the reactance of the elements of the network, and
R2 is the impedance measured across the output.

Let us assume that a resistance R is connected across the output and that the reactance of the coil and of each of the two condensers is equal to R ohms (X = R). In this case, the input impedance would be:

$$R1 = \frac{X^2}{R} = \frac{R^2}{R} = R$$

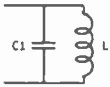
Thus the input impedance is equal to the output impedance. Now assume that the output impedance is reduced to R ÷ 2 ohms; or that it is now just half as large as before. The input impedance becomes:

$$R1 = \frac{R^2}{R \div 2} = R^2 \times \frac{2}{R} = 2R$$

Thus, halving the output impedance causes the input impedance to be doubled, again proving that the network does invert the impedance.

In its simplest form the high-efficiency linear amplifier may be represented by the diagram of Fig. 7. R ÷ 2 is the load impedance into which both tubes will deliver their power. The first tube, or the tube which operates up to the carrier level delivers its power through the impedance inverting network into the load, whereas the peak tube furnishes its power directly to the load. Each tube should work into a load impedance of R ohms for maximum power output. The carrier tube is working into 2R ohms, due to the impedance inverting network, and at the carrier level it is developing as much voltage as possible across this load, the power which it furnishes to the load circuit being just one-half of its maximum capability. This power, however, is being generated very efficiently because the plate voltage swing of the tube is very large. It should be realized that no power is dissipated by the impedance inverting network, because this circuit is composed of pure reactances which cannot dissipate power. Thus, all of the power generated by the carrier tube is being delivered to the load circuit R ÷ 2.

Fig.6 Illustrating that the input impedance is infinite when the output terminals are shorted.



The peak tube is connected directly across the load circuit and naturally will have a plate voltage swing equal to the voltage variation across the load. The actual voltage across the load is just one-half as much as the plate voltage swing of the carrier tube. This may be proved as follows: Let the plate voltage swing

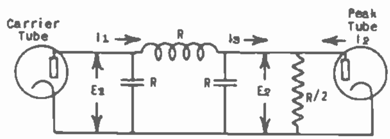


Fig.7 A simplified drawing of the plate circuit of the Doherty amplifier.

of the carrier tube be E1 volts. Then the power which this tube delivers to its load is equal to this voltage squared divided by the impedance into which it works. Since it works into 2R ohms, this power is:

$$\text{Power of Carrier Tube} = \frac{E1^2}{2R} \text{ Watts.}$$

This same amount of power is transferred to the load circuit R ÷ 2, and calling the voltage across the load circuit E2 we have:

$$\frac{E2^2}{R \div 2} = \frac{E1^2}{2R} \qquad \frac{2E2^2}{R} = \frac{E1^2}{2R} \qquad 2E2^2 = \frac{E1^2}{2} \qquad E2^2 = \frac{E1^2}{4}$$

$$E2 = \frac{E1}{2}$$

The peak tube has not, as yet, begun to draw plate current, because of its high bias. Furthermore, the plate voltage swing which it now has is just half as much as it can develop. As the grid excitation voltage to the two tubes rises above the carrier level, the peak tube begins to draw current and at the peak of the modulation cycle, the second tube is saturated, indicating that the voltage across the load has doubled its value. Since the plate voltage swing of the second tube is now maximum, it also is working very efficiently.

Let us now determine what effect the functioning of the peak tube has had upon the operation of the carrier tube. We know that the plate voltage swing of the carrier tube is as large as it can be, and the only way in which it could deliver more power to the load circuit without increasing its voltage swing would be for the load into which it works to be reduced. Let us again consider the conditions existing at the carrier level. The voltage swing of the first tube is twice as great as the voltage across the load; that is, the voltage E1 in Fig. 7 is twice as large as E2. This is shown in graphical form in Fig. 8. It is apparent that as the grid excitation voltage increases from zero up to the carrier level E_0, the voltage E1 rises twice as fast as the voltage E2, and at the carrier level it is twice as large. As the power input to the impedance inverting filter is the same as the power delivered to the load, it is evident that the current I3 (Fig.7) which flows out of the filter into the load must be twice as large as the current I1 which flows from the first tube into the filter.

By reference to Fig. 9 it is seen that as the grid excitation voltage increases from the carrier level up to the modulation peak $2E_0$, the current I3 which flows from the filter into the load does not increase. However, there is now a current I2 which flows from the peak tube into the load. This current increases linearly with respect to the grid excitation voltage from the carrier level up to the peak of the modulation cycle, and at this peak the current from the second tube is equal to I3. Therefore, the total current in the load is twice as great as at the carrier level, and the voltage across the load has also doubled its value.

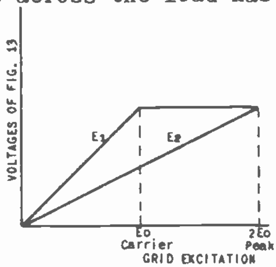


Fig.8 The relationships between the output voltages of the two tubes and the grid excitation.

Although the current through the load has doubled, still the same current is flowing out of the filter, and this action appears to the filter circuit as though the impedance of the load had been increased. The impedance into which the filter works is equal to the voltage across the load divided by the current which the filter furnishes to the load. The voltage across the load had doubled, but the filter is still supplying the same current. Thus, the sensation which the filter experiences is that the load impedance has doubled its value.

As explained before, the filter has an impedance inverting characteristic and since it is now apparently working into a larger impedance, this indicates that the impedance measured across its input is reduced. The impedance across the output was doubled or raised from R÷2 to R ohms. This action caused the input impedance to fall from 2R to R ohms. Thus, each tube is now working into an impedance of R ohms, and each is delivering its maximum power output. The decrease of the load into which the carrier tube was working caused it to deliver more power without increasing its voltage output. The load on the first tube was halved, and with the same voltage output, it is clear that the power delivered by the first tube doubled at this peak. Thus, at the peak of modulation each tube furnished its maximum power and the total power in the load was four times as great as at the carrier level.

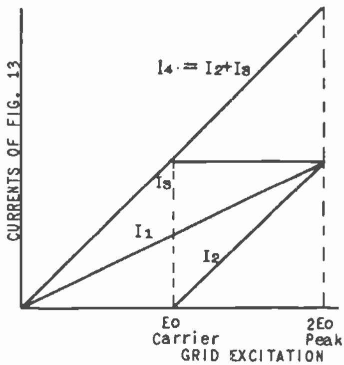


Fig. 9 The relationships between the various currents designated in Fig. 13 and the grid excitation.

Another way of viewing this action is to consider that when the peak tube is not drawing current it has an infinite plate resistance and therefore does not affect the resistance of the load. As the grid excitation increases above the carrier level, the plate resistance of this tube is reduced to a definite value and as may be seen, it is in parallel with the load circuit. Normally, we consider that placing a resistance in parallel with another resistance causes the effective resistance to be reduced; however, the peak tube is a special kind of resistance; instead of absorbing power from the load circuit, it furnishes power to the load. When a resistor absorbs power it is said to be a positive resistance, and this is the type with which we are most familiar. On the other hand, a special type of resistance which furnishes power may be correctly called a negative resistance, since its effects are just opposite to those of a positive resistance. If placing a positive resistance in parallel with another positive resistance causes the effective resistance to be reduced, is it not logical to assume that connecting a negative resistance in parallel with a positive resistance would cause the effective resistance of the two to be increased? This is what actually happens when the peak tube begins to function. Its negative resistance produces a larger effective positive resistance across the output of the impedance inverting network, and thereby creates a smaller resistance for the carrier tube to work into.

There is one other property of this impedance inverting filter which has not been mentioned. It introduces a phase lag of 90°. This means that the voltage E_2 across its output lags 90° behind the voltage E_1 across the input. The plate voltage swing of each tube is 180° out of phase with its grid voltage, and since both tubes are excited from a common source, it is necessary that the excitation voltage applied to the carrier tube be passed through a network which will advance its phase by 90° to compensate for the phase lag in the plate circuit so that both tubes will furnish power to the load circuit in phase, and the power furnished by one will add to that supplied by the other. Therefore, a filter of similar type to that used in the plate circuit is also connected between the grids of the two tubes, as illustrated in Fig. 10. By using two coils and one condenser, the circuit advances the phase by 90° and still has its impedance inverting characteristic.

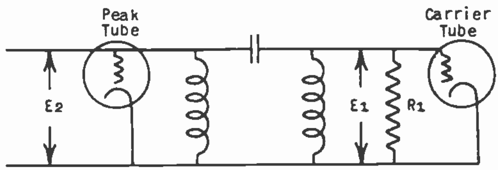


Fig. 10 A simplified drawing of the grid circuits of the Doherty amplifier.

The carrier tube is biased to cut-off and the grid excitation voltage is increased to the point where grid current just begins to flow when the excitation is unmodulated. After the peak tube has begun to function and has decreased the load of the carrier tube so that it can supply more power, it is evident that the increased excitation on the grid of the carrier tube will drive its grid considerably positive with the result that an appreciable grid current will flow. It has been determined that the radio frequency drive of the carrier tube need not increase 100% above the carrier level in order for this tube to supply its share of the peak power. In fact, an increase of only about 40% is required on the positive peaks of modulation. There are a number of ways that could be used to limit the excitation voltage to the carrier tube, but perhaps the simplest is to use a grid leak so that the grid current of this tube will limit the drive by its shunting effect on the exciting source.

Again referring to Fig. 10, it is seen that a resistance R1 is connected across the grid circuit of the carrier tube. When the grid of the carrier tube is not conducting, the voltage E_1 obtained on this grid is equal to $E_2 \times R1 \div X$; where E_2 is the voltage applied to the grid of the peak tube, and X is the reactance of each of the filter elements. When grid current does flow through the carrier tube, R1 is effectively reduced, which causes a diminution in the ratio of E_1 to E_2. The proper value to be used for R1 is not at all critical because of the rapidity with which grid current increases as the exciting voltage approaches the valne which produces maximum power output. Furthermore, as R1 is effectively lowered by the rapidly increasing grid current, the input impedance of the impedance inverting filter is increased, thereby compensating to a large extent for the shunting effect of the grid current in the peak tube as it approaches its peak output power. Due to these actions the grid driving power required for this amplifier is less than for the conventional linear amplifier.

During complete modulation, the average output power of the carrier tube is .93 times the unmodulated value, and for the peak tube is .57 times the carrier. Thus, the total average output of both tubes adds up to 1.5 times the carrier, the factor by which the average power should increase during 100% modulation.

The audio frequency component of the plate current of the carrier tube is nearly sinusoidal so that the plate current of this tube does not vary during modulation. On the other hand, the audio frequency component of the peak tube is nearly a half sine wave, and so the plate current of this tube will depend directly upon the instantaneous percentage of modulation. Since the peak tube is biased to approximately twice cut-off, its plate current pulses flow for less than half of an RF cycle, and the efficiency of this tube starts at about 40%. To cause the overall efficiency of the amplifier to approximate 63%, the peak efficiency of the peak tube must be about 80%.

It is seen that this method of amplification causes a saving of input power of about 50%, and the plate dissipation is correspondingly reduced by a factor of three or four. Furthermore, practical experiments with this type of amplifier have proved that the results obtained approach very closely the theoretical results which were predicted.

3. STABILIZED FEEDBACK FOR RADIO TRANSMITTERS.[1] The output of a perfect radio transmitter, properly rectified and adjusted for volume, would be found to be an exact copy of the speech or signal on its input side. For any actual transmitter, however, the output is found to differ somewhat from the input in three respects. In the first place, the amplitudes of the input and output waves will not maintain the same relative values as the frequency of the input voltage is varied. The second difference is the presence of noise in the output that is not present in the input signal. This noise is principally a hum due to the use of alternating current as the primary source of power for heating the filaments, biasing the grids, and energizing the plate circuits. The third difference between output and input lies in the wave form. When a single-frequency wave is applied to the input, the output includes the harmonics of this frequency as well as the fundamental itself, and thus has a different wave form.

[1] This information is reprinted from the Bell Laboratories Record by courtesy of the Western Electric Company.

The first of these differences is not usually serious, since the frequency characteristic of a broadcasting transmitter can ordinarily be made flat to 1 db over a range from 50 to 10,000 cycles by the proper selection of the low-power audio-coupling circuits, the cost of which is generally less than 1% as much as that of the transmitter. The other two differences are much more formidable, and before the advent of stabilized feedback could be satisfactorily reduced only at considerable expense.

The greater part of both the noise and distortion arises in the final amplifier stages, and for this reason its reduction becomes particularly expensive for the larger transmitters. To reduce the hum, direct-current generators have commonly been employed to supply the filaments, using filters to minimize the commutator ripple. For a 500-kw transmitter, however, a current of some 5000 amperes at thirty volts is required, and the cost of these generators, which must generally be supplied in duplicate, plus the expense of their maintenance becomes considerable. The harmonic distortion, on the other hand, is caused chiefly by the non-linearity of the final amplifying stage. The input-output characteristics of vacuum tubes are not linear up to the limits of their power output, and if to avoid the distortion the tubes were used over only the straight part of their characteristics, considerably greater power would have to be provided in the final stage, and the plate-circuit efficiency would become extremely low.

In the past, engineers have incorporated sufficient tube capacity in the final stage to keep the distortion within tolerable limits, but the initial and operating cost of the transmitter has been proportionately increased. Recent revisions in the standards of performance demanded of radio transmitters have set the requirements on permissible distortion to so low a value that for very large transmitters it becomes economically impracticable to secure sufficiently low distortion by these means. With the increasing size of broadcasting transmitters, therefore, designers are faced with what has seemed the almost impossible task of securing low noise or hum and low harmonic production at a practicable cost. Fortunately, the development of stabilized feedback by H. S. Black has pointed an easy solution. So effective is this new development that the filaments of the tubes may be heated directly from alternating current, and the final amplifiers need only be large enough to carry the modulating peaks, and yet the hum and distortion may be kept well below all likely requirements.

A very much simplified schematic of a radio transmitter might be represented as shown in Fig. 11, where a rectifier is connected to the final stage so that a portion of the output will be available for comparison with the input. For simplicity it may be assumed that the input is a single frequency and under these conditions the input and output voltages could be represented as shown in the lower part of the illustration — the amplitude of the rectifier output being adjusted so that the fundamental frequency has the same value as that of the input to the transmitter. This input voltage is marked Eg, and the corresponding output voltage of the rectifier, although made equal to it by adjustment, is marked Es to indicate that in general it is different from that on the grid of the input stage. Two other voltage values are indicated in the output—one, Ed, representing the distortion voltage, and the other En, representing the noise voltage that is generated within the transmitter itself.

Although Ed and En are actually generated within the transmitter, and in fact, practically always in the final stage of the transmitter, the effect is exactly the same as if these voltages were produced at the grid of the first tube, and the rest of the transmitter were free from distortion and noise. Thus if equivalent voltages 180° out of phase could be introduced into the grid circuit of the first tube along with the signal voltage, the distortion and noise would be cancelled out and the transmitter would be perfect. The principle of feedback is thus to carry back to the input of the transmitter a portion of the output in reversed phase, so that the distorting elements in the output will be cancelled by similar but negative voltages. Actually, of course, the full value of the distortion cannot be completely cancelled, for if it were there would be none of the distortion remaining in the output to be fed back. There must always remain a trace of the distortion in the output that may be adjusted to the proper value and then fed back to the input.

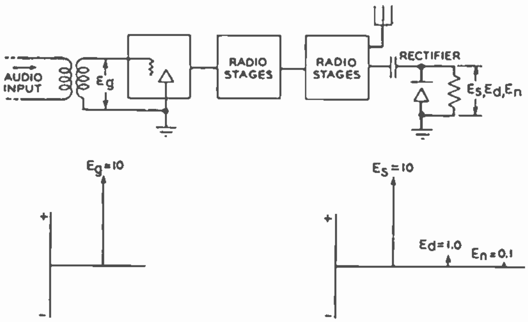


Fig. 11 Outline drawing to illustrate the relative amplitudes of the output signal voltage, distortion voltage, and noise voltage.

The various relationships involved may be illustrated for the moment by considering the harmonic distortion alone, and assuming that without feedback the distortion was 10% of the signal in amplitude, and that it is desired to reduce it to 1% of the signal, or to one-tenth of its former value. This ratio of final to initial distortion defines the amount of feedback required. The distortion under feedback conditions will be equal to the original distortion plus the distortion fed back, which is in phase opposition to the original distortion, and thus the amount of distortion to be fed back will be equal to the difference between the original and final distortion. Thus, if the original distortion was 1 volt and the final distortion is to be one-tenth of that amount, or 0.1 volt, the amount of feedback will be — 0.9 volt, or nine times the final distortion and in opposite phase.

The feedback circuit, however, picks up not only the harmonic-distortion components but the noise and the signal components as well, and all will be reversed in phase and equal to nine times their final values in the output circuits. The purpose of feedback, however, is to reduce the noise and distortion without reducing the signal, but it is obvious that if a signal nine times the original and in opposite phase were fed back, the amplitude of the input signal would have to be changed in order to keep the output signal the same. In other words, the input signal amplitude must be increased so that when combined with the feedback signal, the sum will just equal the original input. Since the signal fed back in the example taken is minus nine times the output signal, the increased input signal must be ten times the original signal in order that the difference will give the same signal amplitude as existed before feedback was applied. If the original signal was ten volts, the signal feedback will be minus 90 volts and the increased input signal must be 100 volts so that the net final signal will be 10 volts, or 100 minus 90.

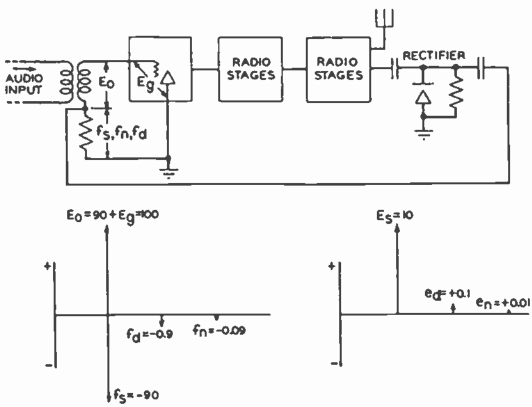


Fig. 12 Simplified drawing to show the manner of obtaining an inverse feedback voltage. The various voltages under feedback conditions are illustrated below.

The amount the input signal must be increased under feedback conditions, or the ratio of input voltage without feedback to input voltage with feedback is numerically equal to the ratio of distortion voltage with feedback to distortion voltage without feedback, and for convenience is taken as the measure of feedback. The amount of feedback in db is thus twenty times the logarithm of the ratio either of the input voltage without feedback to that with feedback, or of the final to initial distortion. In the example taken for illustration this ratio is ten, and thus there may be said to be 20 db of feedback.

In Fig. 12, is shown the same transmitter as in Fig. 11, with the addition of the feedback circuit, and below it are the various voltages under feedback conditions. Small letters are used to indicate the reduced values of the noise and distortion voltages. The noise voltage with feedback, is in the same ratio to the original noise voltage as the distortion voltage with feedback is to the original distortion, all forms of distortion being reduced the same relative amount.

In practice, the phase difference between the input and feedback voltages can be made 180 degrees at one frequency only and the simple, ideal condition just depicted is not realized. It is the problem of the transmitter-circuit designer to control and manipulate the phase shifts and gains throughout the circuits involved so that the feedback and input voltages do not become in phase except at frequencies far removed from the transmitted band. The gain of the feedback loop at these frequencies where the voltages become in phase must be reduced to less than unity or singing will result. It is not always easy to apply feedback to a radio transmitter, but the results obtained with this arrangement cannot be achieved by any other known means which is as simple and economical.

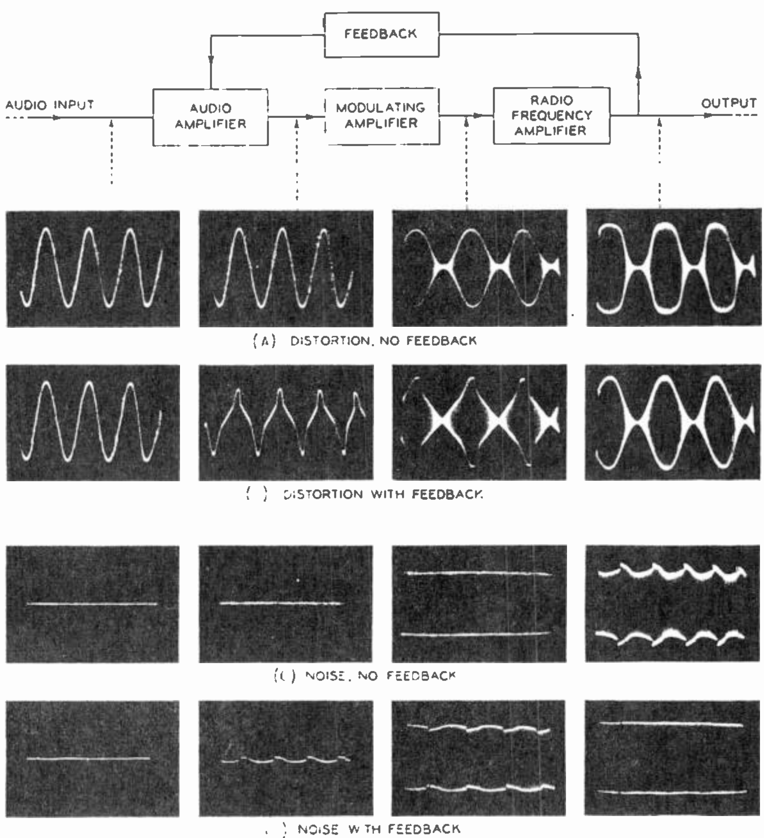


Fig.13 Oscillograms showing the effect of inverse feedback on the distortion and noise content in the carrier wave.

The oscillograms of Fig. 13 show how feedback action deliberately predistorts the audio signal impressed upon the grid of the tube at the point of feedback, and how this predistorted wave, which is in a sense the inverse of the distortion generated within the transmitter, is applied to the various stages. In the series of patterns shown at A, the signal input passes through the transmitter to the output of the modulating amplifier without distortion. Upon passing through the process of modulation and amplification through the Class B linear stages, the wave is distorted and appears in the antenna circuit (output) as shown on the extreme right at A. This wave contains a high percentage of A.F. harmonics, consisting of amplitude distortion of the original A.F. input signal.

When the inverse feedback signal is introduced, the patterns will appear as shown at B. The audio input is still a sine wave, but with the feedback signal also applied to the grid of the first A.F. amplifier, the output waveform becomes distorted. Understand that the distortion components on this audio wave are exactly 180° out of phase with the distortion which will be introduced when the A.F. signal is modulated on the carrier, then amplified to the desired antenna power. Thus, the purposely introduced (feedback) distortion cancels the inherent circuit distortion. The final result of this operation is a modulated R.F. wave in the antenna circuit as shown on the extreme right at B. This wave contains a decidedly reduced percentage of A.F. harmonics in comparison to the radiation wave at A, the result of inverse feedback.

The oscillograms at B and C in Fig. 13 show a similar effect on noise which may be introduced by the radio frequency amplifier. Without feedback the radiated wave is modulated to an undesirable percentage by the noise, but with feedback, the noise signals are almost completely canceled, and the radiation pattern is comparatively pure.

In the case of this particular transmitter, the distortion and noise were purposely made high to portray more vividly the action by means of oscillograms, and, because of the limitations of oscillograms, the change in voltage amplitude associated with the grid circuit where the feedback action occurs has been purposely omitted.

Since the frequency characteristics of radio transmitters are highly satisfactory without feedback, the action of feedback in this respect will not be discussed other than to mention that its amplification also flattens any irregularities of this nature that may exist in the transmitter.

The great advantage of feedback is obvious once its action is understood. The improvement it gives as a result of the large reduction in noise and distortion with a minimum of additional apparatus is of value to listeners as well as to the broadcaster. Of particular importance to the operators of the transmitter, however, is its extreme simplicity. Stabilized feedback is inherently automatic; regardless of the type of distortion or noise generated, the reduction will always be the same without any adjustments being necessary. With a non-automatic method of correction, every change of condition in the transmitter, such as a change in tubes, will require a readjustment, while with stabilized feedback, once the original adjustments have been made at the time the transmitter is installed, no further attention is required.

Fig. 14 shows a simplified schematic of the inverse feedback system as employed in the Western Electric 355E-1 radio transmitter.[1] This feedback system is typical of those employed in all Western Electric transmitters and also typifies the feedback systems which might be employed in other broadcast transmitting equipment.

In order to obtain an output R.F. voltage containing the noise and distortion components, connection is made in the antenna circuit to a point above R.F. ground potential. In Fig. 14 this is the tap at point A on the antenna inductance L1. The R.F. voltage developed between A and B is applied across the primary coil L2 of the R.F. transformer T2. The modulated R.F, signal as fed from the antenna circuit back to the input of the feedback rectifier contains the noise and distortion components. The amount of feedback may be varied by changing the position of tap A on inductance L1. The R.F. signal is modulated, so there will be an audio signal component in the feedback voltage as well as the noise and distortion components.

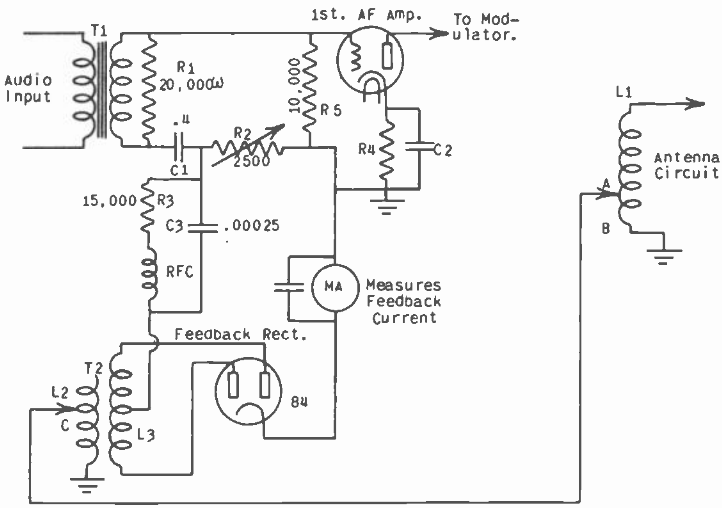


Fig. 14 Simplified schematic of inverse feedback circuit in W. E. 5 KW transmitter.

As the R.F. current passes through the primary coil L2, it sets up a magnetic field which induces corresponding R.F. voltages in L3. This R.F. voltage is rectified by the type 84 full-wave rectifier tube; hence, a rectified-modulated R.F. current is delivered from its output. After rectifying a modulated signal, it is only necessary to filter the R.F. component from the A.F. component in order to completely demodulate the wave. The R.F. choke (RFC) and the by-pass condenser C3 serve to perform this function.

[1] This transmitter will be completely described in the following lesson.

Thus, the audio component, together with the noise and distortion components in the modulated signal, will take the path through R3 and R2 in returning to the cathode of the feedback rectifier tube.

The feedback signal passes through R2, which is connected in series between the bottom of the secondary winding on T1 and the cathode of the first A.F. amplifier in the modulator system. Thus, these feedback voltages will affect the potential appearing between the grid and the cathode of the first A.F. amplifier tube. Also, the grid potential of the first A.F. amplifier is varied by the A.F. input delivered to the primary T1. Consequently, two signals are present in the grid circuit of the first A.F. amplifier, the original audio signal from the speech input equipment and the

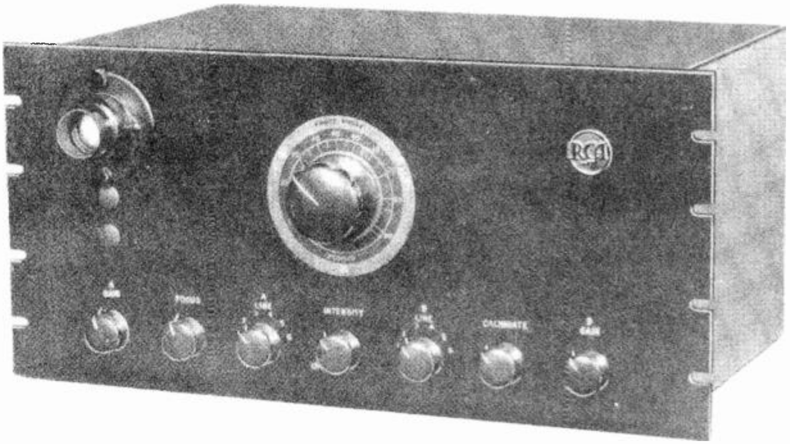


Fig. 15 Photograph of RCA 300-A phase meter.

feedback signal as delivered from the feedback rectifier. These two signals are adjusted to be 180° out of phase and thereby tend to cancel each other. As explained in the preceding paragraphs, the noise and distortion components appearing in the antenna circuit are greatly reduced by this stabilizing feedback system. The magnitude of the feedback current may be adjusted by changing the potentiometer R2. In the Western Electric 355E-1 transmitter, the feedback current is adjusted to 15 ma. for 5 kw. operation.

Whereas slight modifications may be made in this inverse feedback circuit when applying the principle to different types of radio transmitters, fundamentally, the method of introducing the feedback signal and its effect on the amplitude of the radiated noise and distortion will be the same.

4. THE RCA 300-A PHASE METER. The increasing use of directional antenna systems to reduce interference between stations operating on the same or nearby channels has presented some new main-

tenance problems to the broadcast station engineer. To obtain the proper directional characteristics, accurate adjustments not only of the current ratio but also the phase relations of the currents in the various antenna towers is required. While it is possible to measure the current ratios conveniently by use of R.F. ammeters, the requirement of determining the phase angles between the currents in the various antennas has introduced the need for new measuring instruments.

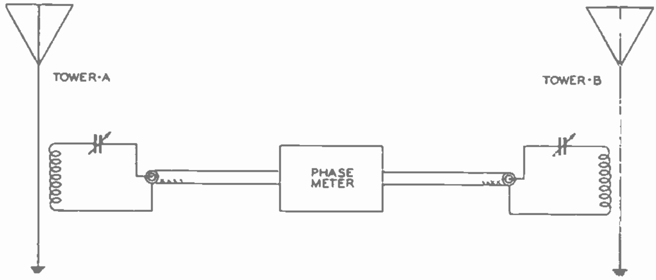


Fig. 16 Showing how R.F. voltages are obtained from antenna towers for the phase meter.

The RCA Manufacturing Company has introduced an R.F. phase meter to the broadcast field in order to cope with those problems which deal with the phase relation between R.F. voltages. The instrument is shown in Fig. 15. The type 300-A R.F. phase meter is capable of measuring all phase angles from 0° to 360° at any frequency between 200 and 1600 kc. While this instrument is extremely useful for many types of R.F. measurements, its primary application is in connection with directional antenna arrays. In such an installation, a small pickup coil is placed near each tower and connected to the phase meter through a transmission line as shown in Fig. 16. The instrument accommodates up to six lines and is provided with switches to enable the operator to select any two lines at a time. Thus the phase angle between the current in any two towers of the array may be measured.

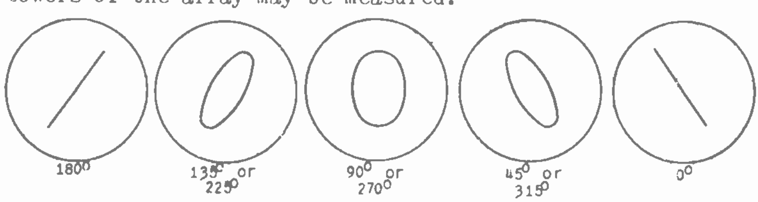


Fig. 17 Oscilloscope patterns obtained under conditions of various phase relations.

In its operation, the phase meter utilizes the ability of a cathode ray tube to indicate with considerable accuracy the phase difference between two R.F. voltages. Fig. 17 shows the patterns which will be obtained on the screen of a cathode ray tube when two applied voltages bear various phase relations to each other. The R.F. voltage from one pickup coil is applied to the horizontal plates of the cathode ray tube (through an amplifier) and the R.F. voltage from the other coil is fed to the vertical plates (also amplified). When the phase relations are such that the two voltages are either in phase or 180° out of phase, the pattern will be a straight line, sloped to either the left or the right, respectively. Between these two extremes, the pattern will appear elliptical in form, being a perfect circle when the phase relation is either 90° or 270°.

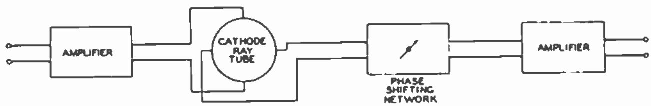


Fig. 18 Block diagram of the RCA 300-A phase meter.

The phase meter circuit consists essentially of two resistance coupled R.F. amplifiers which feed the two sets of deflecting plates of the cathode ray tube. This is shown in block diagram form in Fig. 18. One of the amplifiers contains a calibrated phase-shifting network which may be adjusted to secure an indication of an in-phase condition on the oscilloscope screen. The amount of phase shift introduced to produce an in-phase pattern is equal to the phase difference between the two input signals and is read directly from the dial scale.

The operation of the instrument is not affected by modulation, consequently, measurements can be made at any time while the station is on the air. The input impedance is approximately 80 ohms to match low impedance cables, and the required input signal is less than 1 volt.

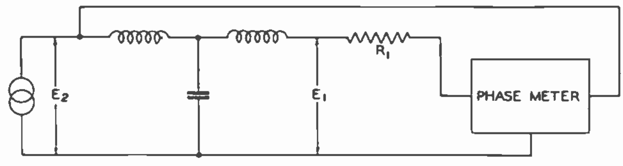


Fig. 19 Typical phase shifting network as used in directional antenna array.

In addition to measuring the phase difference between currents in the various antenna towers, several other measurements are within the scope of the 300-A phase meter. These include: Lining up phase-shifting networks; calculations of mutual impedance of antennas; and impedance measurements of antenna arrays.

In the installation of a directional antenna array, it is always necessary to adjust one or more phase-shifting networks. This is actually accomplished by using an accurately calibrated R.F. Wheatstone bridge. However, it is very desirable to check the final adjustment. A typical phase-shifting network as would be employed in a directional antenna array is shown in Fig. 19. It is a simple "T" section terminated in a resistor. This load resistor is used to simulate the pure resistance offered by a perfectly matched transmission line. In some of the cases where the phase meter has been used to check these adjustments, open-wire transmission lines having a characteristic impedance of 240 ohms have been used. In such cases, R1 is chosen so that when it is placed in series with the phase meter, a resistance of 240 ohms will be offered to the network. Since the phase meter input resistance is approximately 80 ohms, R1 will become 160 ohms. The phase meter then reads the phase angle between the input voltage E2 and the output voltage E1. Since the network is assumed to be pre-adjusted to a pure resistance at the input terminals, the measurement may be regarded as yielding the phase relationship between input and output currents.

In operating the phase meter in the conventional manner, to measure phase relations in a directional array, R.F. voltages from the various pickup coils (one at each antenna tower) are fed to a central point by means of concentric transmission lines where the phase meter is located. If these concentric lines all have equal length, no correction need be made for a time delay occurring in the line. However, when the line lengths are unequal, the time delay or phase shift in the line becomes an important factor. The measurement of this phase shift is a simple matter if it is undertaken before the concentric line is laid in the earth. Fig. 20

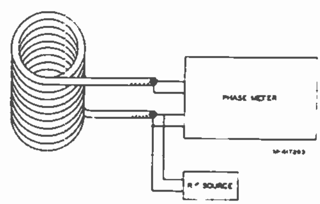


Fig. 20 Showing how the phase shift in a concentric line may be measured with a phase meter.

shows the line coiled up at the phase meter so that both ends are readily accessible. The two ends of the line are connected to two input terminals of the phase meter. R.F. power is then applied to one end of the line. Since the input impedance of the instrument properly terminates the transmission line, measurements of the phase angle between input and output voltages yields the phase delay of the line. By measuring the phase shift in each of the concentric transmission lines used, they may be used as correction factors when operating the phase meter to make actual measurements between the currents in the various antenna towers.

Broadcast stations which employ directional antenna systems will find the phase meter invaluable for maintaining their arrays in correct operating condition. Also, during the initial adjustment of these directional antenna systems the type 300-A phase meter will save hours of labor.

4. WESTERN ELECTRIC 2A PHASE MONITOR. By the use of a directive antenna array, a radio broadcast station can control the distribution of radiated energy to reduce or prevent interference

with other stations. It also can concentrate its program service in selected directions. This may be particularly desirable where the station is not located at the center of the area to be covered.

The adjustment of the electrical circuits of such an array requires a series of field intensity measurements to determine the shape of the field pattern. Experience with this procedure has led to the development of the Western Electric 2A Phase Monitor, an instrument for measuring the phase and amplitude relations of the currents in the antenna elements so that these relations can be correlated with the field pattern.

By the use of this Phase Monitor, initial adjustment can be made more readily from the calculated data while maintenance of adjustment is assured through routine check readings. The instrument is of particular aid to stations that operate with one pattern at night and another during the day in order to meet specific transmission and interference conditions.

The 2A Phase Monitor provides for terminating as many as three sampling lines, originating on small untuned loops on each tower of an array. These lines may be used on a two-tower array to measure the phase angle between the currents in the two towers. On a three-tower array, these lines may be used to measure the phase angles between the currents in each pair of towers. A single control is used to select the desired pair. Additional switching facilities will be necessary if more than three towers are involved. Expanded scale radio frequency milliammeters of the most modern type indicate the true relative amplitudes of the currents in each tower, and a 360° scale measures the phase displacement of the tower currents without doubt as to quadrant. On this scale, leading angles are shown in red and lagging angles in black.

An operator, in a few minutes, can make adjustment for accurate operation on any frequency from 550 to 1600 kc without auxiliary apparatus except for a radio frequency power source of at least 1/5 watt. The phase monitor is self-checking and accurate to well within plus or minus 3 degrees. Small changes in angles may be determined with an accuracy of 1 degree and angles required for established patterns may be set up to within 1 degree.

The radio frequency power required is from 1/5 to 4 watts per tower, depending upon the tower current ratios. The radio frequency power should be obtained from substantial loops rigidly attached to the towers. Because these loops are free from all tuning adjustments, the sampling current remains truly representative indefinitely. Equally simple and reliable means are available for accurately sampling the current in insulated towers.

The 2A Phase Monitor shown in Fig. 21 consists principally of: Two meters for indicating relative amplitudes of tower currents; a phase-measuring condenser and its associated circuit; an amplifier-detector circuit for obtaining an indication of balance; and a self-contained power supply.

The 2A Phase Monitor is quickly installed and adjusted, without the need of external calibrating apparatus. It may be quickly checked at any time when making a measurement. All adjustments are made on the front panel. Initial adjustments are independent of the sampling line currents and the ratio between them. Replacement of tubes does not affect its accuracy.

The apparatus is mounted upon a steel panel covered by a mat occupying $15\frac{3}{4}$ inches of panel space with a depth of approximately $7\frac{1}{2}$ inches and may be located in any convenient place within the station.

Removal of the front mat makes the entire circuit accessible for inspection without removing the instrument from the rack (if it is so mounted) with the consequent necessity for disconnecting the sampling lines. No adjustments of any sort are concealed by this mat. Meters may be tested without removing them from the panel or taking off the mat.

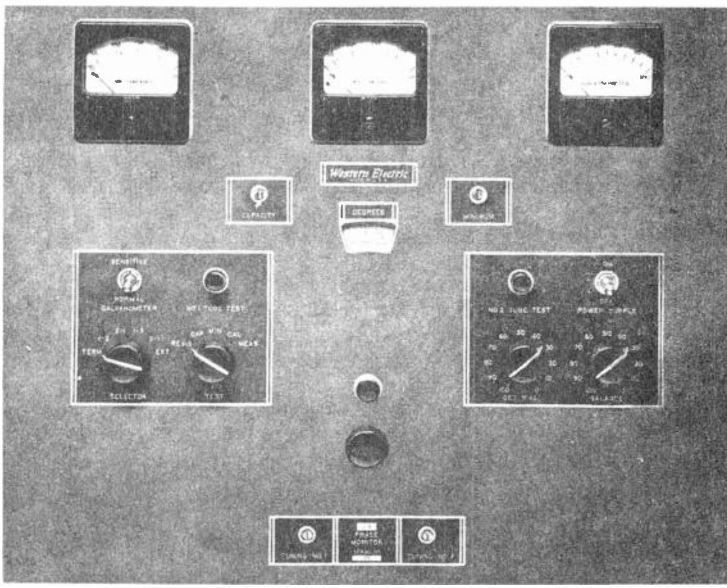


Fig.21 Photograph of Western Electric 2A Phase Monitor.

The tubes, plug-in coils, adjustable resistances, fuses, and sampling line terminals are on the rear of the panel where they are immediately accessible. The heat from the resistances and tubes is dissipated without subjecting other components to excessive temperatures. The coils and variable condensers mounted on the rear of the panel are equipped with easily removable covers. Adjustment to power line voltage is quickly accomplished by changing the position of the fuse.

5. THE RCA 75-B FIELD INTENSITY METER. Measurements of broadcast station field intensities have become increasingly important, both as a means of determining station coverage and as a factor in

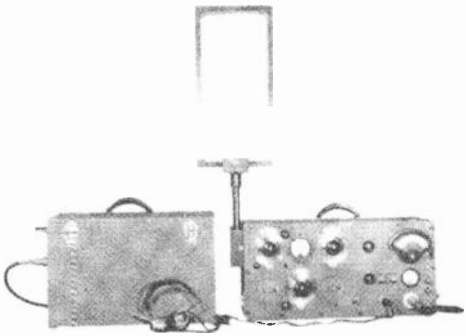


Fig. 22 Photograph of RCA 75-B field intensity measuring equipment.

power and frequency allocations. For this purpose the type 75-B field intensity meter is well-adapted. It is an easily-operated instrument, capable of measuring field intensities with accuracy equal to the importance of the work. A photograph of the complete type 75-B equipment is shown in Fig. 22. This equipment permits an engineer to make surveys, to measure coverage, to select a transmitter site, to determine the radiation pattern, or check the strength of R.F. harmonics.

Since the 75-B field intensity meter is intended particularly for field work, it is designed for battery operation. The complete equipment is carried in two cases and is entirely portable. One case includes the complete measuring equipment while the other has space for batteries, loops and plug-in coils. A type 75-B instrument installed and ready for use is shown in Fig. 23. The manner in which it can be installed in a mobile carrier is shown in Fig. 24.

The controls have been so arranged and grouped as to make the

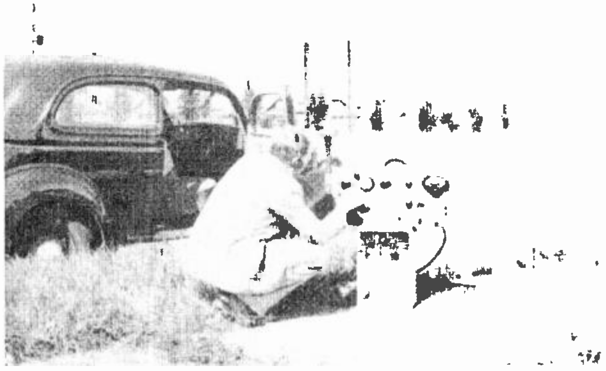


Fig. 23 The 75-B field intensity equipment installed and ready for use.

instrument simple and easy to operate. Because of the method of calibration, the constants of the loop antenna do not have to be measured, so several measuring operations have been eliminated from previous equipment of this type.

All tuned circuits are controlled by means of vernier dials whose vernier ratio may be varied between 6:1 and 20:1. This makes possible easy tuning for the various circuits at high frequencies without too great a vernier action at the lower frequencies.

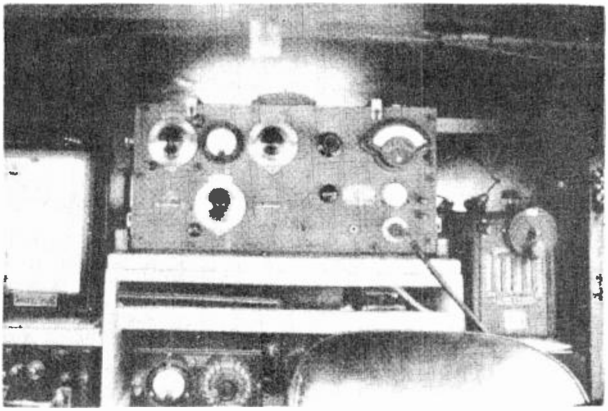


Fig.24 The 75-B equipment installed in a passenger car or small truck.

The instrument will measure signal intensities between 20 microvolts per meter and 6 volts per meter at carrier frequencies between 500 kilocycles and 20,000 kilocycles. It consists essentially of a loop receiver using the superheterodyne principle in which the intermediate frequency operates at 300 kc. A resistor attenuator operating at 300 kc. is provided in the intermediate frequency amplifier to control the gain of the receiver and thereby permit measurements of field strengths over a wide range. Fig. 25 shows a block diagram of the electrical arrangement of the type 75-B field intensity meter.

In order to measure extremely high field intensities, an additional attenuator is provided in the grid circuit of the receiver's first detector. This attenuator consists of C2, R1, and C3 (shown on the schematic drawing in Fig. 26). Switch S2 is provided for switching the additional attenuator in or out of the circuit.

A separate calibrating oscillator and mutual inductor attenuator are provided for the purpose of maintaining the calibration. Four loop antennas are provided to cover the frequency range and four sets of plug-in coils are required.

Referring to the schematic diagram of the 75-B field intensity meter in Fig. 26, the R.F. field signal picked up by the loop at the carrier frequency (500 to 20,000 kc.) is applied to the grid of the RCA 78 first detector, where the frequency is changed to 300 kc. by introducing a voltage from the heterodyne oscillator, which uses a tuned grid circuit and a type 30 tube. The plate circuit of the first detector is tuned to 300 kc. and the secondary of the I.F. transformer (L9) is connected to a variable resistance attenuator, the output of which feeds the input of the first I.F. amplifier consisting of the type 36 tube. The signal is then amplified by the second I.F. amplifier (RCA type 39 tube) and the third I.F. amplifier (RCA type 78 tube), after which it is applied to the diode plates of the type 85 tube for detection. The audio frequency output of the second detector is amplified by the triode section of the 85.

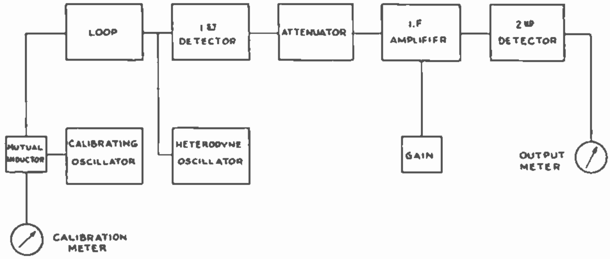


Fig. 25 Block diagram of 75-B field intensity meter.

For the purpose of listening to the signal, a jack (J1) is provided, connected in the secondary circuit of the A.F. transformer T1. Meter M3 is used as visual indication of the output, being connected in the diode detector circuit. This meter remains connected and operates regardless of whether the headphones are plugged into jack J1 or not. The switch S4 is an On-Off switch and the meter M2 is a double range voltmeter. Resistors R4 and R5 are provided for changing the gain of the I.F. amplifier, thereby performing the functions of a volume control.

The calibrating oscillator utilizes an RCA type 30 tube in a tuned plate circuit indicated by L4 and C7. The output of the calibrating oscillator is applied to the primary L2 of the mutual inductor attenuator and a thermo-coupled meter M1 reads the voltage across L2. The coupling between L2 and L1 is fixed, and a reduced voltage appears across L1 which is connected in series with the loop antenna. This voltage acts in the same manner as the signal and is used for the purpose of calibration.

To utilize the instrument in making a field intensity measurement, it is first necessary to adjust the position of the loop antenna and the settings of the various attenuators until a signal at the desired level is heard in the headphones plugged into jack J1 and a reading is obtained on meter M3. Switch S2 may or may not be closed, depending on the strength of the incoming signal. After the loop and all attenuators are adjusted, it is then necessary to use a series of formulas[1] which take into consideration such factors

[1] These formulas will not be given in this lesson since they depend entirely on the individual design of the instrument. For each make and model field intensity meter the manufacturer supplies complete instructions and gives all the necessary formulas for making field measurements.

as the effective height of the loop antenna in meters, the Q of the tuned loop circuit, the conversion conductance of the first detector tube and the gain through the I.F. amplifier as determined by the setting of the attenuator. After all these factors are taken into consideration and the reading on M3 noted, the output of the calibrating oscillator is introduced into the loop antenna circuit. The secondary L1 is in series with the loop antenna, opening the loops at their electrical center. The secondary voltage is directly proportional to the primary current and thus the secondary voltage

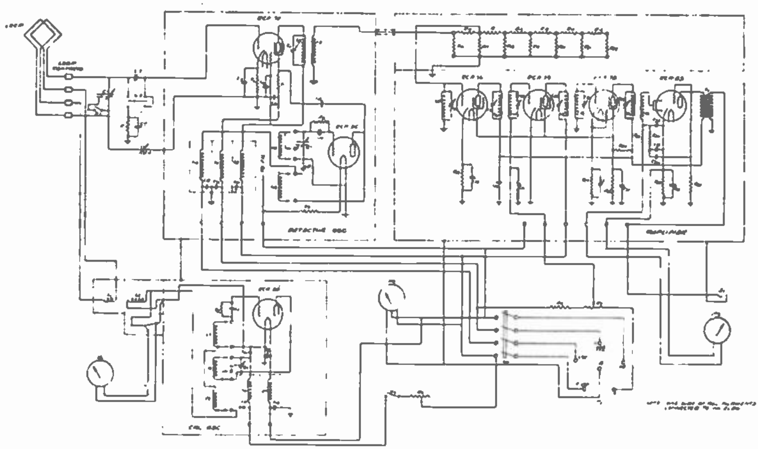


Fig.26 Schematic diagram of 75-B field intensity meter.

will be constant, regardless of frequency, as long as the primary voltage is constant as indicated by the thermocoupled voltmeter M1 across the primary coil. After the known signal from the calibrating oscillator is introduced into the first detector circuit, the attenuator is adjusted to produce identical output conditions as read on meter M3.

All of these adjustments must be performed very carefully if accurate field intensity measurements are to be made. The actual value of the field intensity is then equal to the product of the attenuator setting, the output meter reading, and the loop constants divided by the station frequency. In any particular survey, the last two are fixed, so it is very easy to substitute the attenuator setting and output meter reading in a simple formula to determine the signal strength in microvolts per meter.

After a sufficient number of field intensity measurements are made in all directions from the transmitting antenna, a curve is drawn on a map to show the station's coverage. The standard field signal strength used for plotting coverage maps is .5 millivolts per meter. To draw the curve, points are placed on the map where the measured field intensity was found to be .5 millivolts. It is important to obtain numerous points in all directions from the transmitting antenna; generally every 15°. A line is then drawn connecting all of the .5 millivolt points. The figure thus formed shows the radiation pattern of the station and the surrounding area wherein the signal strength is strong enough to insure consistent reception.

Fig. 27 shows the coverage map of radio station KMBC in Kansas City, Mo. Since this station operates on 5 KW daytime and 1 KW night, two .5 millivolt lines are shown, one for each power. The solid-line circles on Fig. 27 represent the distance in miles from the transmitter and the dashed-lines represent the actual radiation pattern.

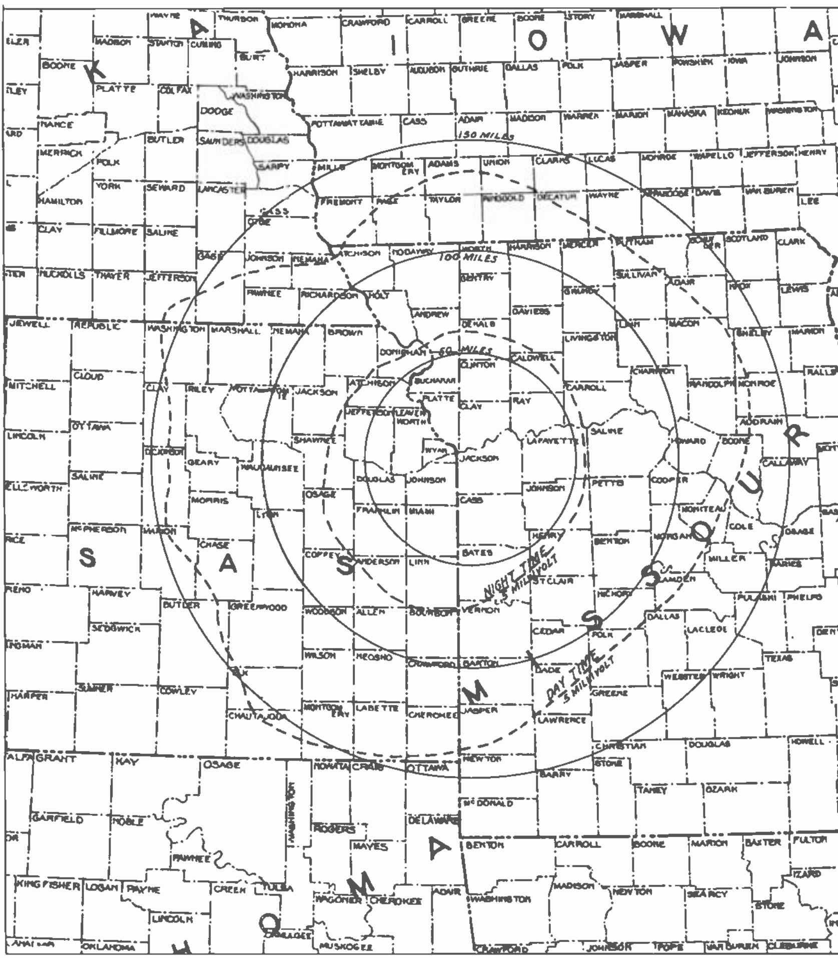


Fig. 27 Field intensity coverage map of radio station KMBC. (Courtesy KMBC and Gallup Map Co. of Kansas City).

6. STANDARD VOLUME INDICATOR AND REFERENCE LEVEL. In recent years it has become increasingly difficult to correlate readings of volume level made by various groups because of differences in the characteristics and calibration of the volume indicators used. This may better be appreciated by considering the communications systems employed for broadcasting. These are very complicated networks spread over a large geographical area. A typical network may include 15,000 miles of wire lines and hundreds of amplifiers situated along the line and in the 50 to 100 connected broadcast stations. Every 15 minutes during the day the component parts of such a system may be shifted and connected in different combinations in order to provide for new points of origin of the programs and for the addition of new broadcast stations and the removal of others from the network. In whatever combination the parts of the system are put together, it is necessary that the magnitude of the transmitted program waves at all times and at all parts of the system, remain within the limits which the system can handle without impairment from overloading or noise. To accomplish this, some convenient method of measuring the amplitude of program waves is needed.

In May of 1939, a new standard volume indicator and reference level was agreed upon by the Columbia Broadcasting System, the National Broadcasting Company, Bell Telephone Laboratories, and more than 24 other affiliated organizations. Briefly, the agreement consisted of: Standardization in the respective broadcast and telephone fields of a new copper-oxide rectifier type volume indicator having prescribed dynamic and electrical characteristics, a new reference level based on the calibration of the new instrument with a single frequency power of 1 milliwatt, and a new terminology, the readings being prescribed in "VU".

Since the primary consideration was the need for an instrument to determine the audio volume of electric voltages in wire lines, it was necessary to not only standardize the VU (volume unit), but also the minute details concerning the construction of the volume indicator instrument itself. First, we shall consider the new standard reference level known as a "VU".

In the past, because of lack of complete understanding of the matter, there has been little uniformity in either the reference level or the volume indicator. As explained in a previous lesson of this unit, reference levels of 1 milliwatt, 6 milliwatts, and 12½ milliwatts have been in common use for audio frequency work. Other variations, mainly in instrument design, consist of RMS or peak indicators, variation of pointer speed, frequency range, and calibration impedance. However, agreement upon instrument design must also include establishing the reference volume level to which the readings are to be referred and agreeing upon the technique of reading the volume indicator.

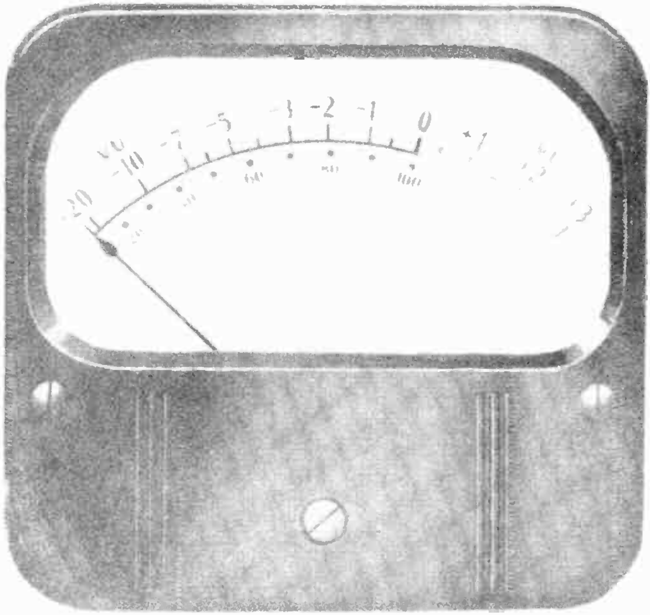
It is important to appreciate that "reference volume" is a useful practical concept, but one which is quite arbitrary and not definable in fundamental terms. For example, it cannot be expressed in any simple way in terms of the ordinary electrical units of power, potential, or current, but is describable only in terms of the electrical and dynamic characteristics of an instrument, its sensitivity as measured by its single frequency calibration, and the technique of reading it. In other words, the correct definition of reference volume is "that level of program which causes a standard volume indicator when calibrated and used in the accepted way to read zero VU". The expression "VU" is defined as "numerical equal to the number of db above 1 milliwatt reference level in a 600-ohm wire line".

It is especially cautioned that reference volume as applied to program material should not be confused with the single frequency power used to calibrate the zero volume setting of the volume indicator. If a volume indicator is calibrated so as to read zero with sine wave power of 1 milliwatt in a standard impedance line of 600 ohms, a speech or program wave in the same impedance whose intensity is such as to give a reading of zero, will have instantaneous peaks of power which are several times 1 milliwatt, and an average power which is only a small fraction of a milliwatt. It is therefore erroneous to say that reference volume in this case is 1 milliwatt. Only in the case of sine wave measurement does a reading of zero VU correspond to 1 milliwatt in a 600-ohm line.

The Type 30 Weston volume indicator is one of the new monitoring instruments whose performance conforms with the standardization. Two types of scales are available with this instrument as shown at A and B in Fig. 28. Each scale is especially designed to best suit a particular application. At broadcasting transmitter plants, the type B scale is generally used. It is arranged with "percent volts" in black figures from 0 to 100 as the principal scale above the arc, and VU levels from -20 to 0 to +3 as supplementary figures in red below the arc. On transmission lines where loss or gain of audio level is of primary importance, (such as studio monitoring), the type A scale is used. It is arranged to show the VU levels from -20 to 0 to +3 as the predominating scale, with values from -20 to 0 being in black and from 0 to +3 in red. Also a supplementary set of figures in black below the arc serve to indicate the percent volts.

The need for marking the scale proportional to VU is obvious but the reason for including the marking proportional to voltage requires an explanation. In a linear system, the voltage scale is directly proportional to percentage modulation of a radio transmitter upon which the program is finally impressed. If the system is adjusted for complete modulation at the time of deflection to the 100% mark, then subsequent indications show the percentage of modulation under actual operating conditions. In the interest of best operation, it may be desirable to adjust the system for somewhat less than complete modulation when 100% indication is reached. In any event the indications of the voltage scale always show the percentage utilization of the broadcast channel. This is a decided advantage because everyone involved has a clear conception of "percentage" indication. Furthermore, since the scale does extend beyond the 100% mark (except in the form of a red warning band), and since it is impossible to obtain

(A)



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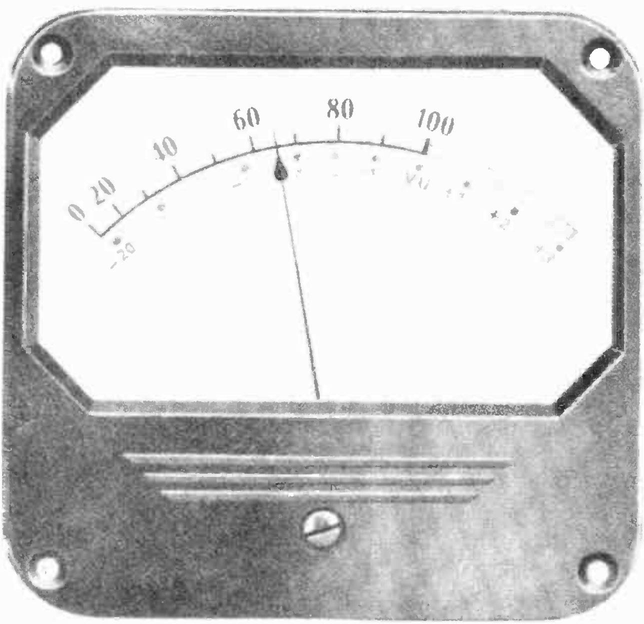
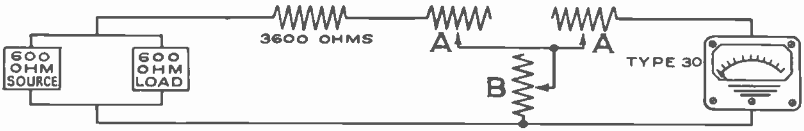


Fig.28 Photos of Type 30 Weston volume indicator, showing two types of scale.

more than 100% utilization of the facilities, there is no incentive on the part of non-technical personnel connected with program origination to request an extra loud effect on special occasions.

The Type 30 VU meter will generally be used with an attenuator arranged to increase the reading at the reference point from the basic reading of +4 VU. to values of higher order (range change attenuator). The attenuator should be of the constant impedance



Attenuator Loss —DB	Level VU*	Arm A Ohms	Arm B Ohms	Attenuator Loss —DB	Level VU*	Arm A Ohms	Arm B Ohms
0	+ 4	0	Open	24	+28	3437	494.1
1	+ 5	224.3	33801	25	+29	3485	440.0
2	+ 6	447.1	16788	26	+30	3528	391.9
3	+ 7	666.9	11070	27	+31	3566	349.1
4	+ 8	882.5	8177	28	+32	3601	311.0
5	+ 9	1093	6415	29	+33	3633	277.1
6	+10	1296	5221	30	+34	3661	246.9
7	+11	1492	4352	31	+35	3686	220.0
8	+12	1679	3690	32	+36	3708	196.1
9	+13	1857	3166	33	+37	3729	174.7
10	+14	2026	2741	34	+38	3747	155.7
11	+15	2185	2388	35	+39	3764	138.7
12	+16	2334	2091	36	+40	3778	123.7
13	+17	2473	1838	37	+41	3791	110.2
14	+18	2603	1621	38	+42	3803	98.21
15	+19	2722	1432	39	+43	3813	87.53
16	+20	2833	1268	40	+44	3823	78.01
17	+21	2935	1124	41	+45	3831	69.52
18	+22	3028	997.8	42	+46	3839	61.96
19	+23	3113	886.3	43	+47	3845	55.22
20	+24	3191	787.8	44	+48	3851	49.21
21	+25	3262	700.8	45	+49	3857	43.86
22	+26	3326	623.5	46	+50	3861	39.09
23	+27	3384	555.0				

Fig.29 Wiring diagram of Type 30 Weston VU meter, with table showing values of arms A and B for various reference levels.

type in both directions in order that the instrument's dynamic characteristics may be maintained independent of the attenuator setting. Fig. 29 illustrates the wiring of the attenuator. The accompanying table gives the values of the arms A and B for various reference levels up to +50 VU. The table is based on a zero reference of 1 milliwatt in a 600-ohm line (zero VU).

EXAMINATION QUESTIONS

INSTRUCTIONS. Before starting to answer these examination questions, you should have studied the lesson material at least three times. Be sure that you understand each question--then proceed to write the best answer you can. Make all answers complete and in detail. Print your name, address, and file number on each page and be neat in your work. Your paper must be easily legible; otherwise, it will be returned ungraded. Finish this examination before starting your study of the next lesson. However, send in at least three examinations at a time.

1. What is the greatest disadvantage of the conventional type of linear amplifier?

2. Does the load impedance on the carrier tube increase or decrease when the grid excitation is above carrier level? How much?

3. Why is the peak tube in a Doherty amplifier biased to twice cutoff?

4. What is the advantage of using a stabilized feedback system on a radio transmitter?

5. Why is it necessary to rectify the feedback voltage when it is obtained from the antenna circuit?

6. What provision is made on Fig. 3 for regulating the feedback current?

7. Name two uses for a phase meter (or phase monitor).

8. What are the uses of a field intensity meter?

9. What is the new standard unit adopted for measuring the audio level in program wire lines?

10. Is the percentage modulation of a carrier wave directly proportional to the modulating AF voltage or the modulating AF power?

Notes

(These extra pages are provided for your use in taking special notes)

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UNIT NO. 4	WESTERN ELECTRIC 1 KW AND 5 KW TRANSMITTERS	LESSON NO. 10

WHAT MAN CAN IMAGINE

.....he can do.

A famous writer, who has now passed on, frequently used the above expression and offered proof of a substantial nature that it was true.

Many of the conveniences that we enjoy today, and accept as commonplace, have been created through the imagination of man. For years and years previous to the Wright Brothers' historic flight at Kittyhawk, Virginia, man imagined that he could fly. Queer flying 'contraptions' were constructed. A few firm believers in the ability of man to soar through the air like a bird, even went so far as to jump from cliffs with wings attached to their bodies. Needless to say, they failed to soar and crashed to the ground with disastrous results.

In spite of failure after failure, man's imagination persisted. He continued to dream of the day when he would startle the world by flapping his way into the air. Finally man's efforts were partially rewarded. He did soar in strange looking gliders. And then came the great day when a man actually flew in a flying machine powered with a gasoline engine.

As we know today, all of these pioneers of aviation were looked upon as impractical dreamers. And if they had limited themselves to 'dreaming' they would have been impractical. But they backed up their dreams and imagination with action.....they were 'doers' and they did it.

Today there are many, many dreamers in this world; men who dream of success and imagine what they would do with all the money they see in their dreams. However, they will never feel or spend any of that money, for they fail to back up their imagination with ACTION. They are not 'doers'.

No doubt you too have dreamed of success and let your imagination run wild. But you are doing more than that. You have taken ACTION. You are a 'doer'. Keep up your good work, and remember, 'WHAT MAN CAN IMAGINE, HE CAN DO'.

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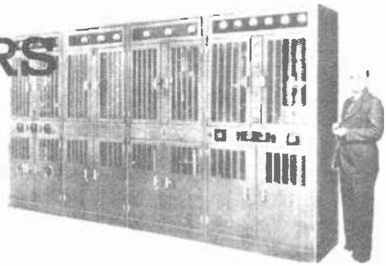
Lesson Ten

W.E. 1&5 KW TRANSMITTERS



"In this lesson, I shall describe the Western Electric 355E-1 transmitting equipment, a popular broadcast transmitter for stations operating on a 5KW daytime and a 1KW night schedule.

"While studying this lesson, concentrate particularly on the discussions pertaining to operating procedure and maintenance. These will be of great importance to you in your daily work as a radio operator.

"This lesson concludes your study of Unit Four on commercial Broadcast Station operation. Upon securing your First Class Radiotelephone operator's license you will be well qualified for employment in the broadcast field."

1. INTRODUCTION. The 355E-1 Radio Transmitting Equipment consists of the following elements: A quartz crystal controlled oscillator operating into two buffer amplifiers driving a modulated amplifier consisting of two tubes in push-pull; followed by a Class "B" linear amplifier stage consisting of two tubes in push-pull combination; with the necessary plate and grid supply rectifiers and associated power apparatus. These elements are combined for generating a constant frequency carrier which may be modulated by a broadcast program signal, for amplifying the modulated carrier and transmitting it to an antenna where it is radiated.

The unmodulated carrier power which is normally supplied to the antenna from the radio transmitter is 5 kilowatts. For night operation, the antenna power may be reduced to 1 kilowatt without break in the program by reducing the plate, bias, and excitation voltages on the final stage.

Approximately 28 kilowatts is drawn from a 220-volt, three-phase, 50 or 60-cycle power supply at a power factor of 0.95 to operate the equipment.

The process of modulation takes place in the transmitter at a relatively low power level, the grid bias method being employed. The distortion contributed by the process of modulation and amplification in the radio transmitter is exceptionally low.

Radiation on harmonics of the carrier frequency is reduced to a negligible amount by the type of output circuit employed and by the use of shielding in the transmitter.

Protection against accidental contact with high voltage is provided by the control circuit and the manner in which the apparatus is assembled. The transmitter units are completely enclosed and are equipped with doors which cannot be opened with voltage on, nor can dangerous voltages be applied with the doors open. This applies also to the door of the enclosure to the high voltage rectifier apparatus. In addition to removing the high voltages, the doors to the power amplifier and rectifier enclosures are provided with interlocks which require grounding of the high voltage parts.

The operation of the transmitter is controlled by means of circuits and relays associated with the toggle control switches mounted on the front panels of the transmitter cabinets. The transmitter may be automatically started and stopped by means of one of these control switches and the operating condition of the various circuits is indicated by a group of signal lights.

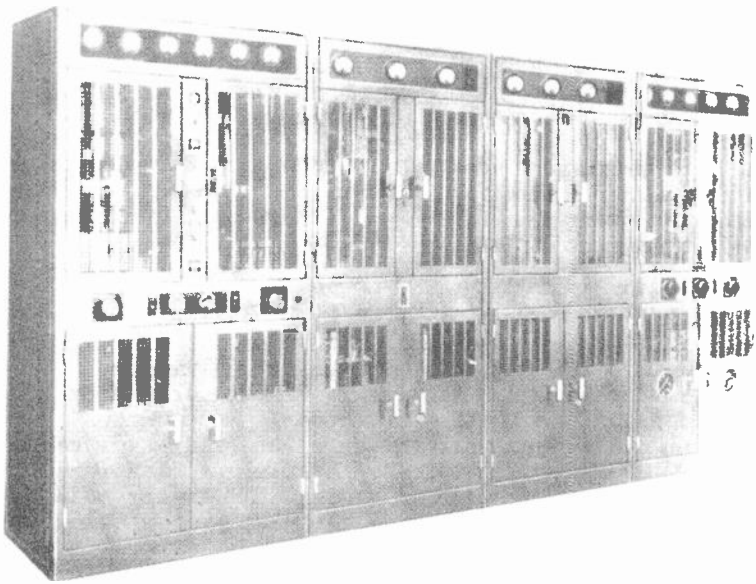


Fig.1 Front view of 5KW W. E. 355E-1 Transmitter.

2. DESCRIPTION OF APPARATUS. The apparatus comprising the radio frequency circuits of the transmitter is mounted in three cabinets which are intended for assembly on the main floor of the transmitter building. These cabinets should be mounted together to form a continuous panel front. A fourth cabinet containing the control equipment can be mounted together with these units or separately as desired. Figure 1 shows a general view of the complete

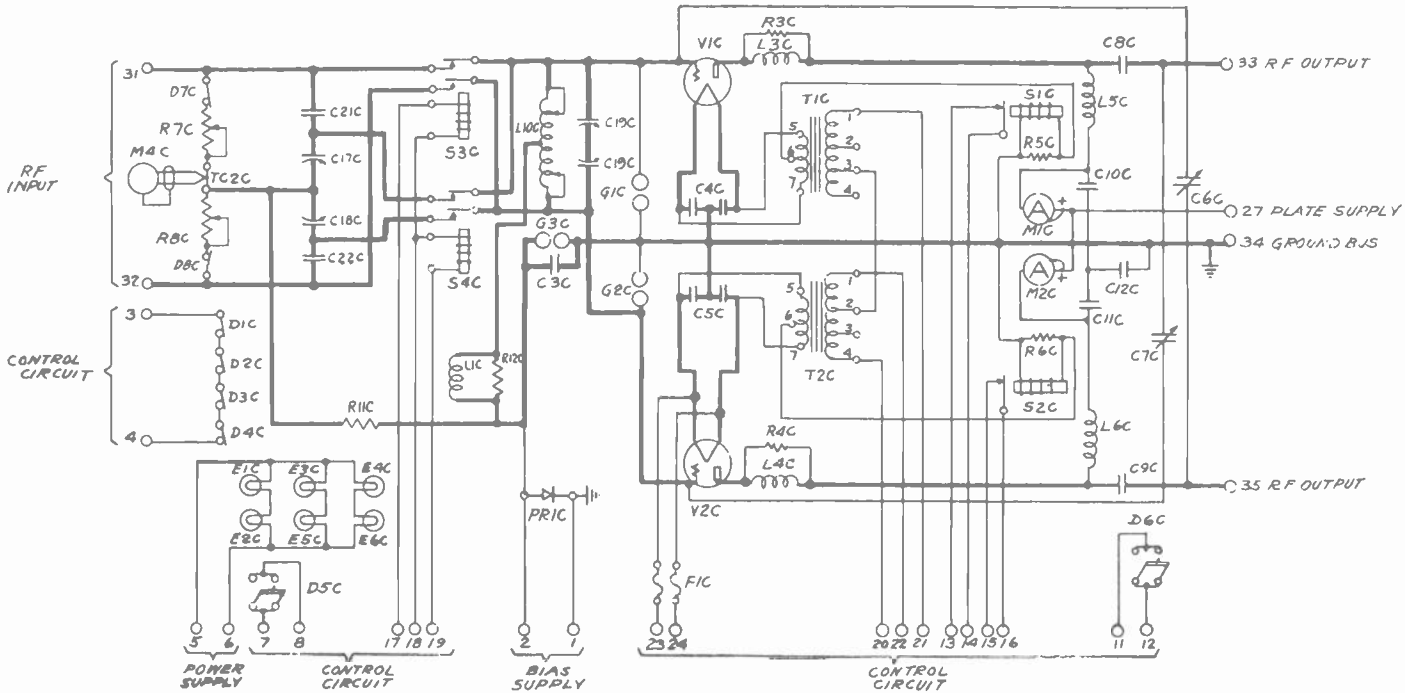


Fig. 2 - Modified D-98654 Power Amplifier Tube Unit - Schematic

5 KW transmitter. The high voltage rectifier, water cooling equipment and antenna coupling unit are grouped and installed as necessary to function.

To facilitate reference to particular pieces of apparatus, each piece is designated by a combination of two letters with a numeral between them such as C3A. These designations are used throughout the text of this lesson and on the drawings. In the units of the transmitter, these designations are marked either on the piece of apparatus itself or adjacent to it. The first letter of the designation indicates the type of apparatus. For example, a condenser is designated by the letter "C". The number distinguishes between pieces of apparatus of the same type located in each unit. The last letter refers to the unit in which the apparatus is located according to the letter classifications given below. The letters designating the several types of apparatus are:

C - Condenser
D - Switch
E - Indicator Lamp
F - Fuse
G - Spark Gap
L - Inductance
M - Meter
MB - Motor - Blower
P - Protector
Q - Pressure Guage
R - Resistance
S - Relay
T - Transformer
TC - Thermocouple
V - Vacuum Tube
VS - Vacuum Tube Socket
X - Rectox Rectifier
Z - Water Valve

The letters assigned to the units and assemblies of apparatus are:

A - D-98653 Oscillator-Modulator Unit
C - D-98654 Power Amplifier Tube Unit
D - D-98655 Power Amplifier Tuning Unit
E - D-96898 Antenna Coupling Unit
F - D-98656 Control Unit
G - D-98473 Rectifier Tube Unit
P - Power Apparatus
W - Water System
Y - 700A Oscillator Unit

(A) Transmitter Unit Assembly. The first three main transmitter units are contained in metal cabinets with doors in front providing access to the interior. As mentioned before, these cabinets should be mounted side by side to form a continuous panel front. The Control Unit, which is of the same general appearance as the other transmitter units, may be placed in line with these three units or it may be located separately in any convenient position as might be dictated by the individual requirements of the station. These four units are as follows:

D-98653 Oscillator-Modulator Unit - (described in Lesson 12, Unit 3). The No. 700A (Quartz Crystal Controlled) Oscillator is inserted in this unit. The buffer amplifiers for the oscillator and the modulating amplifier are located in this unit together with the grid bias and plate supply rectifiers and control apparatus for these amplifiers. A two-stage audio amplifier and a feedback rectifier are also located in this unit.

D-98654 Power Amplifier Tube Unit - (Schematic: Fig. 2). Two No. 220B water cooled tubes are mounted in this unit, together with input circuit, DC plate circuit apparatus, and a filament transformer for each tube.

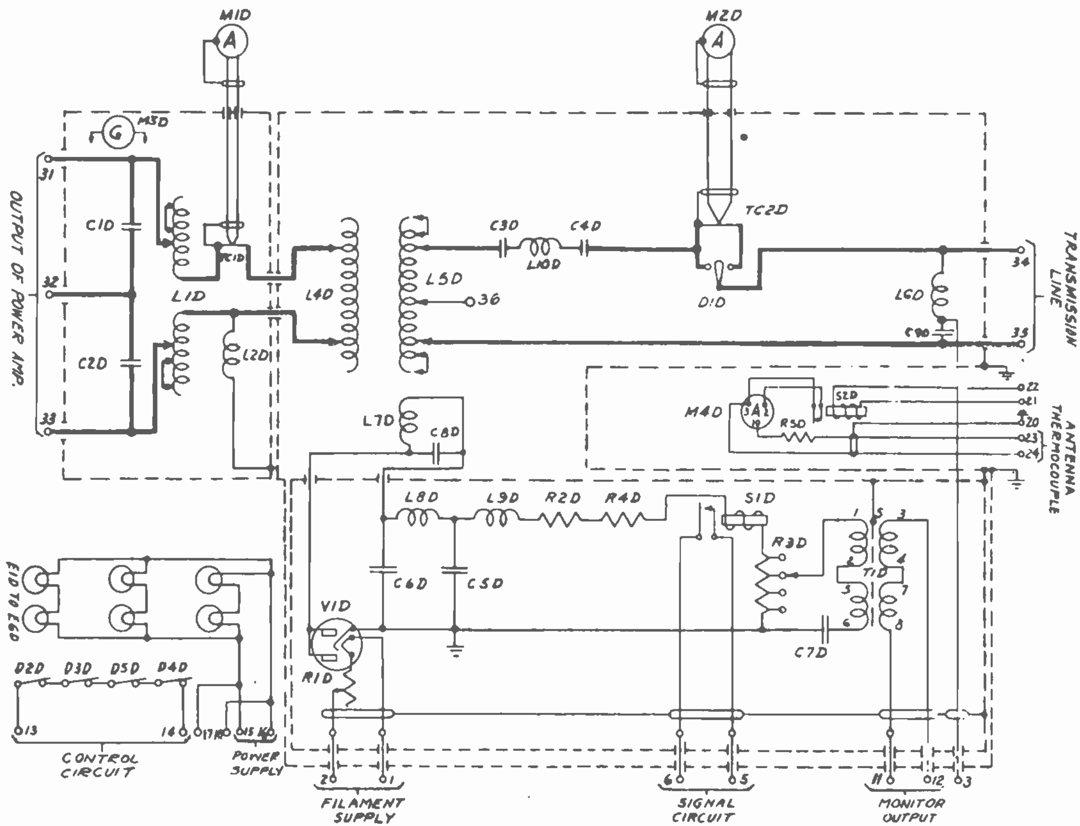


Fig. 3 - Modified D-98655 Power Amplifier Tuning Unit - Schematic

D-98655 Power Amplifier Tuning Unit - (Schematic: Fig. 3). The tuned output circuit of the power amplifier for connection between the power amplifier tubes and the radio-frequency transmission line is assembled and shielded within this unit, together with a monitoring rectifier.

(B) D-98656 Control Unit. (Schematic: Fig. 4.) The major elements of the control system which supplies power in the proper sequence to the various parts of the entire radio transmitting equipment are located in this unit as are the bias rectifier for the power amplifier and the signal lamps with their associated relays.

(C) High Voltage Rectifier Assembly. This assembly consists of the D-98473 Rectifier Tube Unit (Schematic: Fig. 5), filter, transformers, contactors and switches. Normally the oil filled transformers and filter coil are placed outdoors, but if conditions so dictate, these too may be located with the rectifier tube unit indoors. This apparatus is assembled in an enclosure as best suited to the individual requirements of the station.

(D) Antenna Coupling Unit Assembly. The D-96898 Antenna Coupling Unit (Schematic: Fig. 6), forms part of the output circuit of the transmitter, providing an adjustable element between the antenna and transmitter terminations. The antenna coupling unit is connected to the transmitter by a co-axial radio-frequency transmission line. The coupling unit contains an antenna grounding switch, a high and a low current antenna ammeter, a coupling device for the antenna ammeter on the Tuning Unit and safety and control switches.

(E) Water Cooling and Power Equipments. Water Cooling Equipment (Schematic: Fig. 8). This equipment consists of porcelain hose coils, forced draft radiator, flow meter and pump for the water system used for cooling the anodes of the power amplifier tubes.

(F) Power Equipment. (Schematic: Fig. 9). The power distribution panels and contactors, the plate supply transformers of the rectifier tube assembly and a rectox unit for supplying DC for the control circuit are grouped as Power Equipment.

3. DESCRIPTION OF CIRCUITS. The following description of the circuit of the radio transmitting equipment is taken up through analysis of the complete circuit into its component parts such as the power circuit, the control circuit, the radio-frequency circuit, etc. These component circuits usually extend through several of the transmitter units. The identification of a particular part of a circuit and its association with a particular unit or group of apparatus is readily made by the apparatus designation.

(A) Power Circuits. The power circuits and power apparatus of the equipment are shown on the Interconnecting Wiring Schematic, Fig. 7. The power service from the three-phase 220-volt supply is connected in the power distribution panel to the line switch D1P. An auxiliary supply which may be the 110-volt station lighting circuit is connected to terminals 24A and 25A to provide a continuous

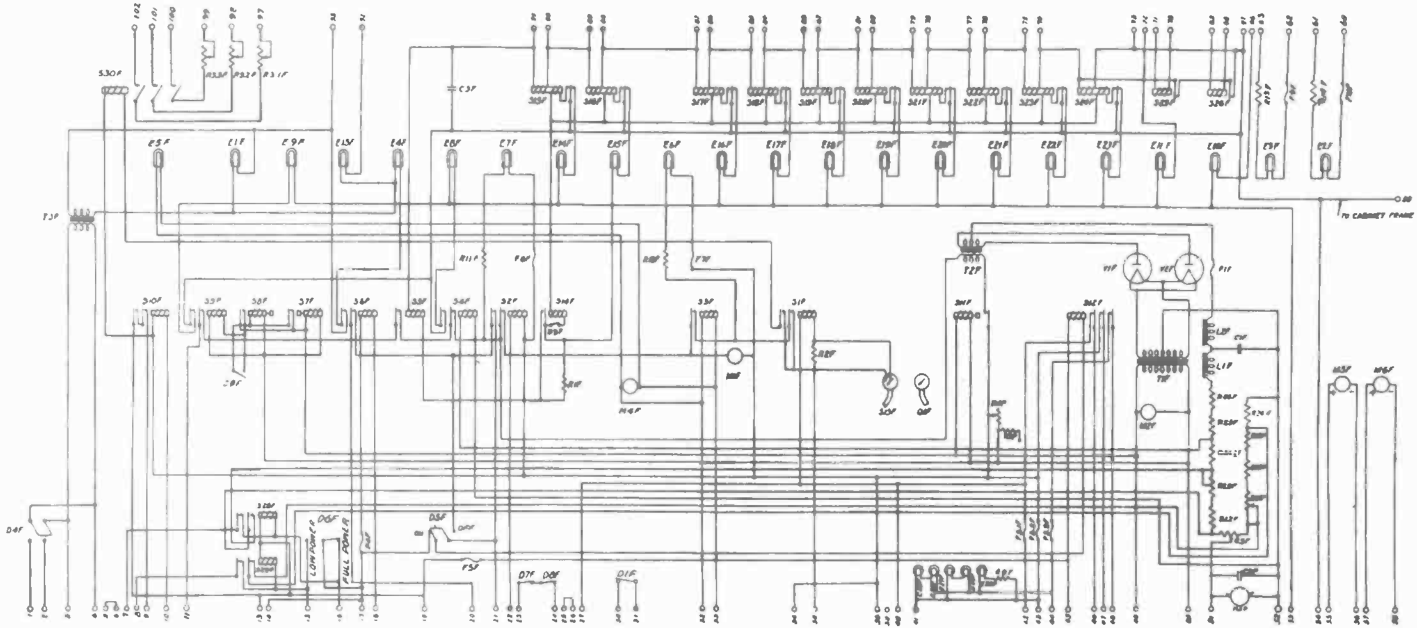


Fig. 4 - Modified D-98656 Control Unit - Schematic

source of power for the heater unit of the No. 700A Oscillator.

From the power distribution panel, a single phase branch supplies power through the Master Control Switch D4F (refer to Fig. 9) to operate the Oscillator-Modulator Unit and to the transformer T3F for some of the signal lamps.

A three-phase branch to the Control Unit supplies power for the bias rectifier, the high-voltage rectifier filaments, meter panel lights, the blower MB1G in the rectifier tube assembly and for the control circuit of the power amplifier. Still another three-phase branch supplies power to the rectifier plate transformers T1P, T2P, and T3P through the plate primary contactor S1P. A final three-phase branch supplies power through the contactor S3P to the filament transformers, water pump and radiator blower. The latter two items are equipped with thermal cut-out switches at the respective motors.

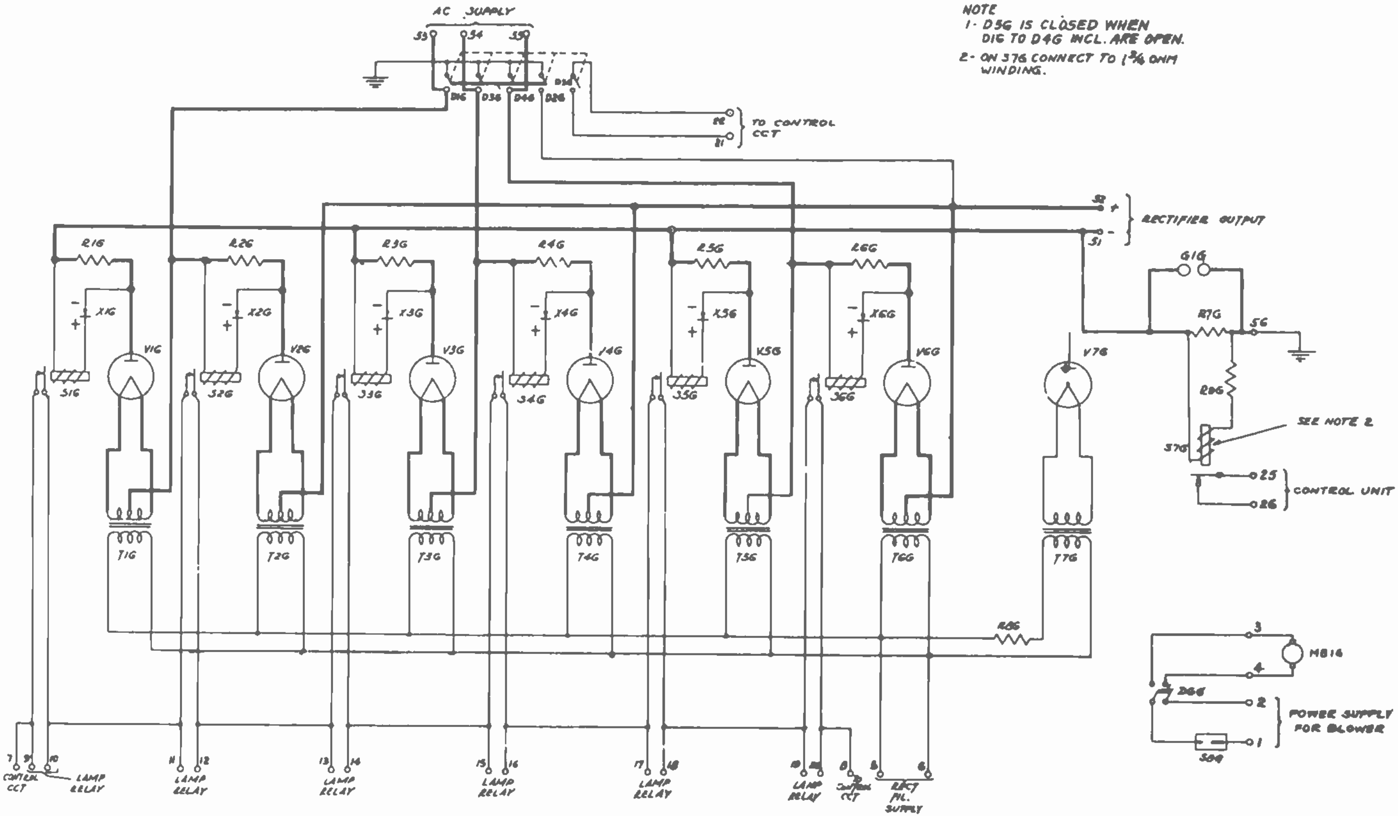
The power supply for the primaries of the filament transformers goes through a ganged rheostat R3F for adjusting the filament voltage and a contactor S30F which opens the filament supply in case of a failure in the water system. The filament transformer T1C and T2C are Scott-T connected to provide a two-phase supply for the power amplifier tubes. A branch circuit from the secondary of T1C supplies the filament of V1D as well as indicates the filament voltage (M4F), completes a link of the control circuit (S3F), and gives a signal lamp indication (E5F).

The grid bias rectifier with its associated filter consisting of retard coils L1F and L2F and condensers C1F and C2F and its voltage dividing resistors R19F to R26F and R5F is located in the control unit.

The plate supply for the power amplifier is obtained from a three-phase, full-wave rectifier employing six No. 315A Vacuum Tubes. These rectifier tubes together with their filament transformers, arc-back relays, air cooling equipment and the DC overload relay are mounted in the No. D-98473 Rectifier Tube Unit (Fig. 5). The primary voltage of filament transformers for these tubes is maintained at 200 volts by means of the rheostat R6F in the Control Unit (terminals 49 and 50 in Fig. 4). This voltage is measured on M2F.

The high voltage supply for this rectifier is obtained from transformers T1P, T2P, and T3P. Primary overload protection is afforded by the two current transformers T4P and T5P, and the associated relays S25F and S26F. (Fig. 9). D2P is a disconnect switch. S1P is a double contactor. The operation of S1.1P connects the proper taps on the primaries of T1P, T2P, and T3P to make available an output voltage of approximately 12 kilovolts for 5 KW operation. The operation of S1.2P connects the proper taps to make available an output voltage of approximately 5.4 kilovolts for 1 KW operation.

Relay S1G through S6G (Figs. 9 and 5) are arc-back relays. Between these relays and their shunts are connected small copper-oxide rectifiers (X1G to X6G) so poled that the relays are not operated by the unidirectional current through the shunts under normal operating conditions. When one of the tubes arc-back, alternating current will flow through the shunt and the alternating potential



NOTE
1- D5G IS CLOSED WHEN D1G TO D4G INCL. ARE OPEN.
2- ON S7G CONNECT TO 1¾ OHM WINDING.

Fig. 5 - Rectifier Tube Unit - Schematic

produced, rectified by the rectifier, will operate the relay. The operation of an arc-back relay causes the control circuit to open the plate transformer supply contactor S1P and to extinguish the proper signal lamp indicating the tube in which the arc-back occurred.

Protection against a DC overload is obtained by means of relay S7G with its shunt R7G.

The filter circuit for the high voltage rectifier consists of the retard coil L1P and the condensers C1.1P and C1.2P. A resistor R2P is connected in series with the two filter condensers in order to limit the charging current during starting. After these condensers have been charged, R2P is short circuited by the magnetic switch S2P.

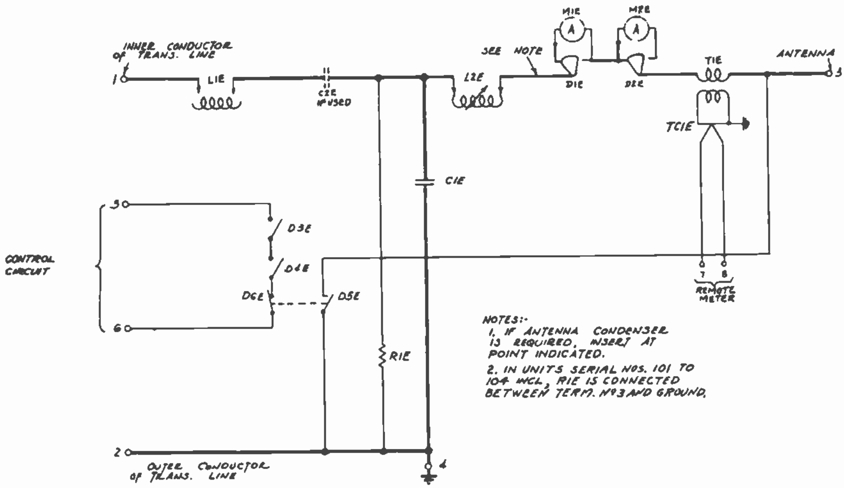
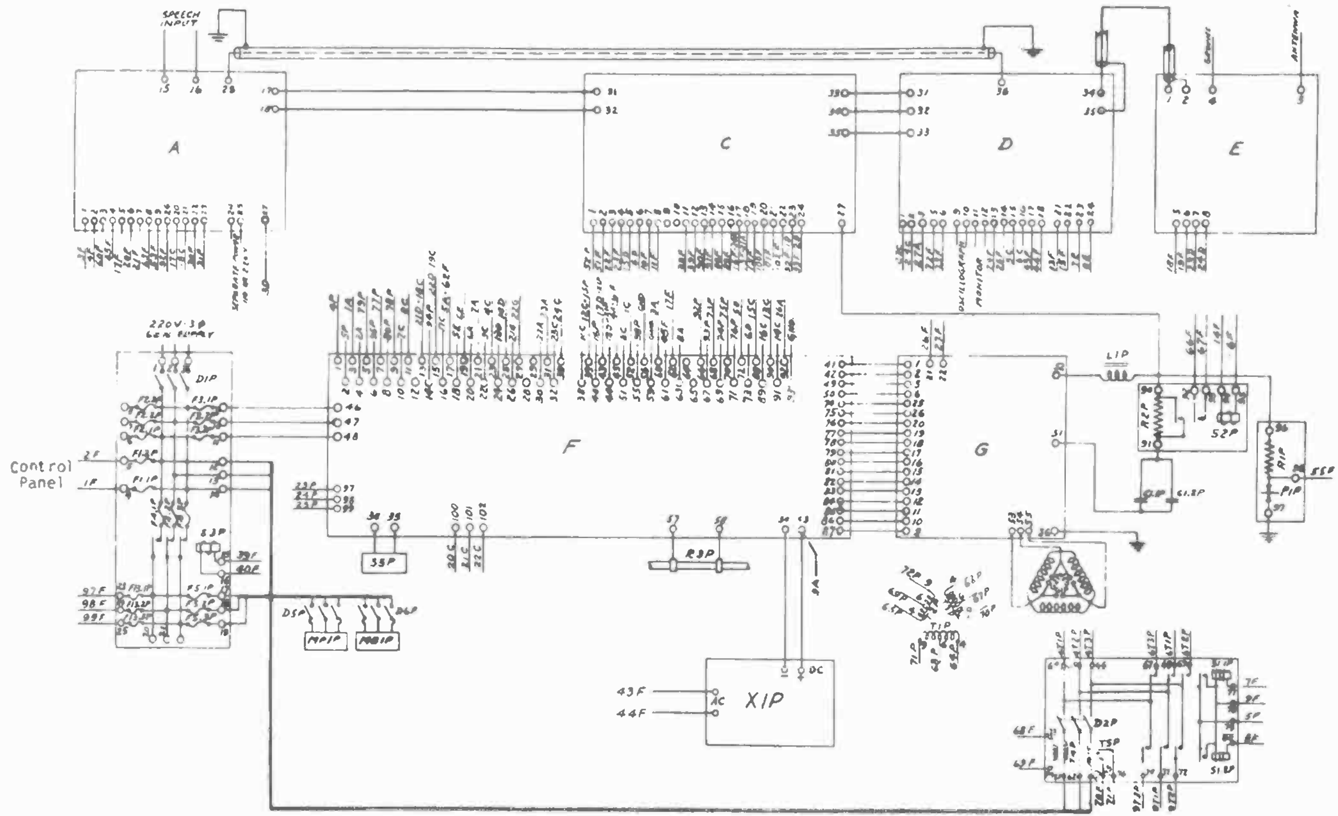


Fig.6 The D-96898 Antenna Coupling Unit.

The air system consisting of the blower MB1G, thermostat S8G, Switch D6G, and the necessary piping, is provided to cool these rectifier tubes in case of high ambient temperature.

The safety ground switch with blades D1G, D2G, D3G, and D4G, and auxiliary contacts D5G, is located at the top of the rectifier tube unit and is thrown by means of a handle outside of the door of the high voltage rectifier enclosure.

When the handle of this switch is thrown to the safety position, it functions first to open the primary contactor, S1P, and, as the handle is moved to the end of its travel, finally grounds the secondaries of the plate supply transformers and the high-voltage DC bus of the rectifier. A key interlock is associated with the handle of this switch. When the switch is in the safety position, keys are released which may be used to open the doors to the enclosure and to the power amplifier tube and tuning units. The switch cannot be removed from its safety position until all doors have been closed and locked and the keys returned to the interlock at the switch handle.



7 - Radio Transmitting Equipment Interconnection Diagram

(B) Control Circuit. The Control Unit contains the major elements of the control system which supplies power in the proper sequence to the various parts of the entire radio transmitting equipment.

The following discussion of the operation of the control circuit to supply power to the transmitter refers to the schematics of the individual units and the interconnecting wiring schematic. The schematic of the Power, Control and Protection System shown on Fig. 9 may also be referred to. In order to simplify this figure, certain minor changes have been made in the arrangement of connections.

This transmitting equipment has been designed to operate when so desired at a reduced power level (1 kilowatt) by reducing the plate, bias, and excitation voltages on the final stage. The change from full power to reduced power or vice versa may be made by operating the "Power Transfer" switch on the Control Unit. In order to start or stop the power supply equipment for the final amplifier the "Power Amplifier Control" switch is operated.

This equipment will operate satisfactorily on a three-phase 60-cycle supply at 220-240 volts. For the purpose of the following information, 220 volts is assumed. The incoming power supply is connected to terminals 1P, 2P and 3P on the Power Distribution Panel. Switch D1P closes this circuit to the major part of the bussing system of this panel as shown on Fig. 7, A single phase branch through fuses F1.1P and F1.2P supplies terminals 1 and 2 of the Control Unit (Fig. 4). By closing the "Master Control" switch D4F, 220 volts is supplied to the primary of transformer T3F, causing lamp E1F "AC Supply" to light. At the same time, power is supplied through terminals 3F and 4F to terminals 1 and 2 on the Oscillator-Modulator Unit. (Fig. 8, Lesson 12, Unit 3 and Fig. 9 of this lesson.) If the knife switch D10A and the "ON" button D9A are both closed, power is supplied through transformer T8A to terminals 4 and 5 which are connected to the control unit through terminals 45F and 17F (Fig. 7) respectively.

The starting and protection circuits of both the Oscillator-Modulator and the Power Amplifier units are interlocked and the complete equipment can be started or stopped by operating the "MASTER CONTROL" switch (D4F) located on the Control Unit. The "MASTER CONTROL" switch (D9A) located on the Oscillator-Modulator unit actuates the starting circuit which applies power to the circuits of the Oscillator-Modulator in the correct sequence, introducing such delays as are necessary for the protection of the equipment.

The auto-transformer T8A which supplies power to all circuits of the Oscillator-Modulator is provided with a tap switch "POWER VOLTAGE CONTROL" (D6A) which allows the operator to compensate for variations in the local line voltage during operation of the transmitter.

When the filament heating period for the rectifier tubes in the Oscillator-Modulator unit is terminated, the bias-plate rectifier transformer T5A is energized. Signal lamp E2F "Osc. Mod. Filament" in series with resistor R14F and fuse F10F is connected effectively in parallel with T5A for indication. In a similar man-

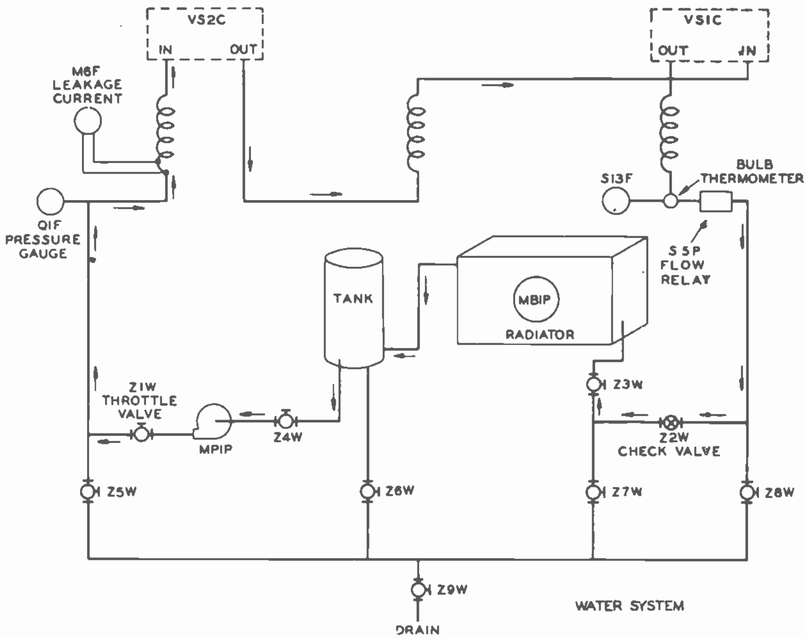


Fig.8 Schematic, D-96847 Radio Transmitting Equipment Water System.

ner, the presence of primary supply to the plate voltage rectifier T4A is indicated by lamp E3F, "Osc. Mod. Plate" through resistor R13F and fuse F9F.

When the plate overload relay S4A is in normal position, its back contact (connected to terminal 26A) completes a ground return circuit to light lamp E13F "Osc. Mod. Overload". When an overload has occurred to close S4A, this lamp is extinguished. The holding circuit of the relay may be broken to restore the plate voltage by pressing either reset button D4A or "Osc. Mod. Overload Reset" D1F, at the option of the operator. With the modulated amplifier self-biased, overloads will not normally be experienced in this circuit.

If the "Power Amplifier Control" switch D5F (Fig. 9) is thrown to the "ON" position, 220 volts will be applied to relay S12F. This relay closes a 220-volt, 60-cycle, three-phase circuit from the distribution panel through terminals 46F, 47F, and 48F to energize the major portion of the Power Amplifier Control System. The filament transformers supplying filament power to rectifier tubes V1F, V2F, and V1G to V7G, inclusive, are energized immediately through the "Rectifier Filament Rheostat" R6F which should be adjusted to read 200 volts on meter M2F. The meter panel lamps on the panel of this unit and those of the Power Amplifier tube and Tuning Units should light. Power is supplied to the Rectox Unit X1P (Fig. 9). Voltage is supplied from this bus to terminals 39F and 40F through the "Emergency Tube Change" switch D6C connected between terminals 38F and 39F to energize the coil of the motor starting contactor

S3P on the Power Distribution Panel. The closing of this contactor supplies power through fuses F5.1P, F5.2P, and F5.3P to energize the water pump motor MP1P and the water cooling radiator fan MB1P, supplied through overload tripping disconnect switches D5P and D6P, respectively. As soon as the water flow rises to normal value, the water flow relay S5P closes a circuit between terminals 34F and 35F to energize water flow relay S1F through resistance R2F. Should the temperature of the cooling water become excessive, the water temperature relay S13F short-circuits the winding of S1F, causing it to drop out until the temperature is reduced. The closing of the right contact of S1F closes S30F which completes the circuit to the filament transformers and energizes the filaments of the power amplifier tubes V1C and V2C. When these filaments are lighted, relay S3F closes, which supplies 220 volts to the terminals of filament hour meter M1F through the closed left contacts of S1F. The operation of the latter contacts is indicated by lamp E6F "Water System".

Referring to Fig. 9, the control voltage is supplied to the gate switch chain including gate switches on the high voltage rectifier, the doors of the power amplifier tuning unit, the lower doors of the control unit (switches D7F and D8F) and the doors of the power amplifier tube unit. If these door and gate switches are all closed, the winding of S2F is energized. The closing of the right-hand contact of this relay causes lamp E7F "Gate Switches" to light and supplies power to the grid bias plate transformer T2F if the contact of delay relay S11F has been closed. S11F is provided to prevent the application of plate voltage to the bias rectifier tubes V1F and V2F until their filaments have attained operating temperature, a period of approximately 45 seconds. When the bias rectifier is energized, it supplies DC to the bias load resistors R19-26F and R5F through the filter consisting of retard coils L1F and L2F, and condenser C1F. R5F is used as a variable potential divider to supply correct bias voltage to the power amplifier tubes. Further filtering of this supply is provided by condenser C2F. Meter M3F indicates the value of the bias output voltage. When this voltage reaches proper value, grid bias marginal relay S4F closes. The right contact of this relay closes the 22-volt DC circuit supplied from the Rectox X1P through terminals 53F and ground to light lamp E8F "Bias Rectifier". The left contact of S4F continues the control circuit from the right contact of S2F to the contact of S5F, the overload circuit relay. Under normal circumstances, this relay will be in the closed position. Further discussion of the operation of this relay will be found later. The control circuit is then continued to the left contact of S9F, the AC filament auxiliary relay.

Relay S7F is connected across the filament supply to the high voltage rectifier tubes. When this supply has been energized for a period of 5 minutes, S7F operates which energizes S8F and S9F. In case of a momentary power failure of less than eight seconds, S8F maintains its contacts closed so that the delay for S7F to operate and complete the control circuit is eliminated. In case of power failures up to several minutes duration, the "Emergency Delay Re-

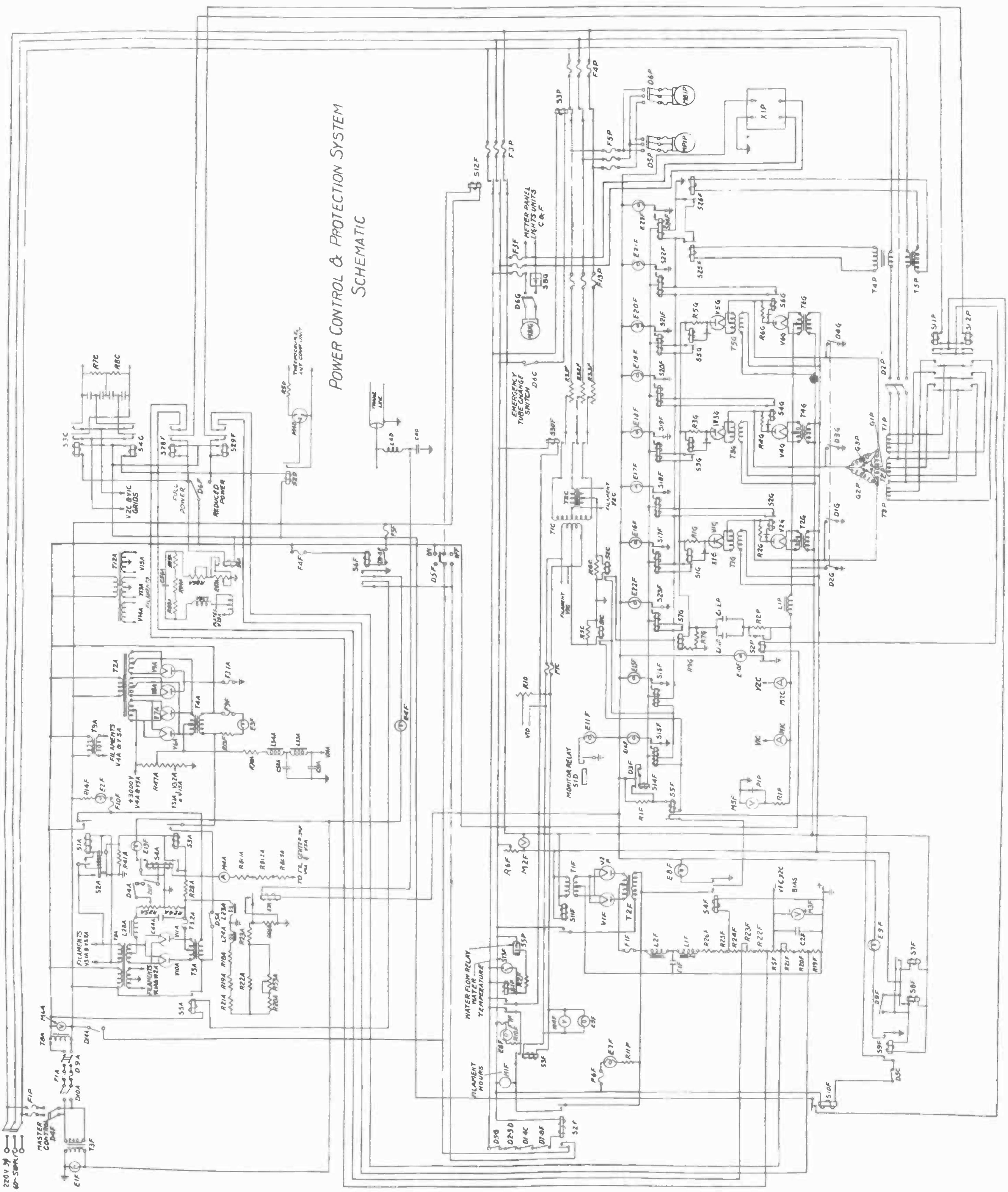


Fig.9 Radio Transmitting Equipment Power Control and Protection System - Schematic.

lease" button "D9F" may be pressed momentarily to pull up S8F. In either case, high voltage will not be applied to the rectifier until after the delay of S11F (45 seconds) has energized the bias rectifier. This "Emergency Delay Release" should be used only in case of emergency as the reduced heating effect will result in a somewhat shorter life for the 315A Rectifier Tubes.

When the AC filament auxiliary relay S9F closes, the control circuit is continued through the high voltage rectifier switch D5C (connected to terminals 11F and 10F) to close the rectifier control relay S10F. The latter relay in turn closes one side of the 220-volt control circuit to operate the plate supply contactor S1P. As will be explained under the discussion of changing power, the particular selection of S1.1P or S1.2P depends on the position of D6F "Power Transfer Switch". This contactor is provided with a delay interlock which after a delay of approximately one second, depending upon its setting, closes the circuit through terminals 14F, 6F and 5F to energize the high-voltage filter condenser resistor contactor. When this contactor closes, its auxiliary contact closes the 22-volt DC circuit to light lamp E10F "Condenser Switch".

The 220-volt three-phase 60-cycle supply to the high-voltage rectifier is obtained directly from the distribution busses in the Power Distribution Panel. This supply enters the rectifier switching units on terminals 61P, 62P and 63P. (Fig. 7.) T4P and T5P (Fig. 9) are primary overload tripping transformers which cause the overload circuit to open the rectifier primary supply contactor S1P whenever an AC overload occurs. Switch D2P is a disconnect switch. The primaries of transformers T1P, T2P and T3P are connected in delta by contactor S1P. The operation of S1.1P makes the delta connection to the proper taps to give an output voltage of approximately 11,500. The operation of S1.2P selects the taps for an output voltage of approximately 5400. The high-voltage rectifier employs a three-phase full-wave (or bridge) connection. The DC high-voltage output of the rectifier is connected through filter choke L1P to the filter condensers C1.1P and C1.2P and the high-voltage plate terminal 27C on the power amplifier tube unit (Fig. 2). The charging current of these condensers is limited by resistance R2P (Fig. 9) during the charging period. After a delay of approximately one second, this resistance is short-circuited by the main contact arm of S2P and the filter is in full operation. In order to measure the DC voltage output of the rectifier, the voltmeter multiplier R1P is connected to the high-voltage output terminal of the filter. The associated voltmeter M5F is located on the control and the operator is protected from contact with high voltage, in case the meter or its connections become open circuited, by a protector P1P connected between the low potential end of the multiplier and ground.

Each of the power amplifier tubes is provided with an overload relay in the center tap of the filament transformer which will operate when a current of 2.5 amperes is exceeded in the plate circuit of the vacuum tube to which it is connected. High voltage relays are connected in the plate circuits of each of the high-voltage rectifier tubes. The latter relays are supplied with rectox units so poled that they will operate only when the associated rectifier tube fails to rectify. This condition is known as an "arc-back". Relay S7G, (Fig. 5) the DC overload relay, located in the rectifier unit and connected in the negative lead of the rectifier, functions when an overload occurs in the high-voltage DC circuit. The contacts of each of these 9 relays are connected to short-circuit the operating windings of the 9 lamp relays S15F to S23F (Fig. 9). In addition, the series connected contacts of the AC overload relays S25F and S26F normally short-circuit the windings of lamp relay S24F. S25F and S26F are connected to tripping transformers T4P and T5P, respectively, mentioned above. When an AC overload occurs, contacts of one or both of these relays open. When one of these relays operates, the operating coil of its lamp relay is inserted in series with the winding of the overload circuit relay S5F causing it to drop out. This breaks the control circuit of the plate transformer contactor S1P, thus removing plate voltage from the transmitter. At the same time the particular lamp relay involved operates to extinguish the associated indicating lamp and energizes the relay holding coil.

The holding coils of all of the lamp relays are connected through winding of relay S14F to the positive terminal of the 22-volt DC supply. The latter relay operates to insert resistance R1F in series with the winding of S5F. As soon as the plate voltage has been cut off by the opening of contactor S1P, the overload relays return to normal, but the lamp relays affected hold, maintaining resistor R1F in series with S5F, thus preventing its operation. The circuit remains in this condition until the power amplifier reset button D3F is pressed. The holding windings of the affected lamp relays and the winding of relay S14F are thus de-energized, the relays return to normal, and the indicating lamps relight as soon as the reset button is released.

The transmitter may be operated at 1 KW or 5 KW output, depending on the excitation, bias, and plate voltages on the final stage. These voltages are all changed as required in changing from one power to the other by the operation of D6F "Power Transfer" switch. The 220-volt control circuit for the oscillator modulator unit is supplied to terminals 17F and 45F. The circuit from 45F is through the contacts of S10F to the common side of the windings of S28F and S29F and through 13F to the common side of S3C and S4C. From 17F, the circuit is through D6F. In the full power position of D6F the circuit is completed to S28F and through the outer contacts through 7F to S1.1P. The operation of S28F short circuits the bias resistors R22F and R23F. This adjusts the bias to approximately 200 volts. In the full power position of D6F the circuit is completed through 16F to S3C. The operation of S3C connects the grids of V1C and V2C directly across the input terminals 31C and 32C for full excitation voltage (Fig. 2). If D6F is thrown to the "Reduced Power" position S28F releases and S29F closes (Fig. 9). This releases S1.1P and puts S1.2P in condition to be operated by S10F. S29F short circuits R20F and R21F reducing the bias to approximately 90 volts. With D6F in the reduced power position, the circuit is completed through 15F to S4C. The operation of S4C connects the grids of V1C and V2C to points on the input capacitors so that the excitation is reduced. The circuit is also completed through 15F and 13F to S2D the operation of which increases the sensitivity of M4D to read the antenna current at reduced power.

(C) RADIO-FREQUENCY CIRCUITS.

(a) Oscillator-Modulator Unit. A description of the R.F. circuits in this unit is given in Lesson 12, Unit 3.

When the Oscillator-Modulator is used as a 100 watt transmitter, the output of the third amplifier is coupled to the antenna through an antenna coupling circuit for the suppression of radio frequency harmonics. However, when the Oscillator-Modulator is used in conjunction with a Power Amplifier, the output circuit is slightly modified and becomes the power amplifier input circuit.

(b) 5 KW Power Amplifier Tube Unit. The Power Amplifier is a neutralized push-pull circuit. The input circuit, the tubes V1C and V2C, the plate chokes and the neutralizing condensers are located in the Power Amplifier Tube Unit, shown in Fig. 2. The input circuit consists of load resistors R7C and R8C shunted by C17C, C18C, C21C, and C22C. The operation of S3C connects the grids of V1C and V2C across the complete input circuit. The operation of S4C connects the grids across C21C and C22C so that the excitation is less. Bias is supplied to the grids through L1C to the midpoint of L10C which is tuned to anti-resonance with C19C. C3C is the grid blocking condenser and C4C and C5C are the filament by-pass condensers. C6C and C7C are the neutralizing condensers; C8C and C9C the plate blocking condensers. R3C-L3C and R4C-L4C are plate anti-sing assemblies. R11C and R12C are stabilizing resistors. L5C and L6C are plate choke coils. S1C and S2C are overload relays operating across shunts R5C and R6C, respectively. M1C and M2C are plate current ammeters. C10C and C11C are by-pass condensers for the meters. C12C is the plate by-pass condenser.

(c) Power Amplifier Tuning Unit. The tuned output circuit of the power amplifier is located in this unit, shown in Fig. 3. The first mesh of this circuit consists of C1D, C2D, L1D, and L4D, the primary of the intermesh coupling transformer. L1D is divided in two sections. M1D measures the current in this mesh by means of external thermocouple TC1D. L2D is a static drain coil. The second mesh consists of L5D, L10D, C3D and C4D. The current in the second mesh is measured by means of M2D and its external thermocouple TC2D. L6D and S7A (on Fig. 9) normally constitute a static drain. The function of L6D and S7A as part of the transmission line protective circuit is discussed later. M3D (Fig. 3) is a radio-frequency galvanometer which may be inserted in the first mesh during neutralization of the power amplifier. The second mesh output is connected to the transmission line to the antenna coupling unit. A tap on L5D provides an r-f voltage for the feedback rectifier.

Monitoring equipment is also located in this unit. L7D of the monitor is coupled to L5D of the second mesh. V1D is the monitor rectifier tube, R1D the filament rheostat. Condensers C5D and C6D and coils L8D and L9D form a radio frequency filter. Audio Transformer T1D connected across R3D provides an audio-frequency output which may be used to operate a monitoring amplifier in the speech input equipment. Relay S1D, operating on the DC component of the rectifier output, gives a signal light indication.

(d) Antenna Coupling Unit. The apparatus for coupling the antenna to the radio-frequency transmission line is located in this unit, shown in Fig. 6. L1E is the transmission line coil, C1E the coupling capacity and L2E the antenna coil. M1E and M2E are antenna current meters for full power and reduced power respectively. Switches D1E and D2E take these meters out of the circuit except for periods of tuning or inspecting this circuit. T1E is a coupling device which with thermocouple TC1E allows the antenna current to be read on M4D located in the D-98655 Power Amplifier Tuning Unit. D5E is the antenna ground switch and R1E is a static drain resistor.

(e) Transmission line Protective Circuit. In the event that a severe transient condition causes a flash arc in the transmission line, the transmission line protective circuit functions to remove the carrier drive and thus prevents the transmitter from maintaining the arc and damaging the line. 24 volts DC is supplied from the rectox unit X1P through the operate winding of S7A and through the radio-frequency filter section made up of L6D and C9D to the inner conductor of the transmission line. This circuit is shown on Fig. 9. When a flash arc occurs in the transmission line the arc, due to its high conductivity, completes the 24 volt DC circuit and operates relay S7A to insert R95A in series with the ground return of the voltage divider of the bias supply for the first and second amplifier stages of the oscillator-modulator unit. These stages are then biased beyond cut-off which removes the carrier drive and extinguishes the arc. Relay S7A then restores itself to normal position, the carrier drive is reapplied and normal transmission is resumed. The lapsed time for this complete cycle is a fraction of a second.

(f) Water Cooling System. The water cooling system is shown diagrammatically on Fig. 8. The functions of the portion of the cooling equipment in the Power Amplifier Tube Unit are to remove the heat dissipated from the anode of the vacuum tubes in this unit and to protect these tubes against damage due to an interruption in the flow of water. Insulation between the tube jackets and the rest of the water cooling system is provided by the ceramic coils outside of tube unit. In order that a check may be kept of the insulation resistance of the water, meter M6F is provided to indicate the leakage current through one of the water coils.

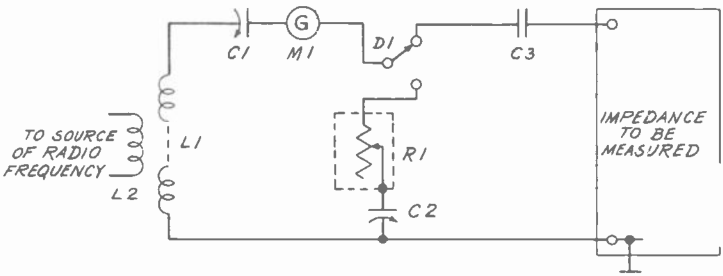
Water from the storage tank is forced by pump MP1P through the tube jackets in the Power Amplifier Tube Unit. This water is then cooled by passage through the forced draft radiator MB1P and returned to the storage tank.

The temperature of the water leaving the tube unit is indicated by thermometer dial S13F located in the Control Unit. The contacts of this thermometer are connected in the control circuit, functioning to shut off the plate and filament voltage supplies to the vacuum tube if the temperature of the water becomes excessive. The water pressure at the input to the first ceramic coil is measured by the pressure gauge Q1F in the Control Unit.

4. ADJUSTMENT OF RADIO-FREQUENCY CIRCUITS. The following information on the adjustment of the radio-frequency circuit assumes that the units of the transmitter have been installed correctly and that all inter-connections between them are complete.

(A) Antenna Coupling Unit. The antenna coupling unit should be tuned prior to the transmitter proper in order that a load circuit will be available for the adjustment of the transmitter.

When the antenna coupling unit is adjusted so that its input impedance is equal to the characteristic impedance of the transmission line, the line will be "properly terminated" and no standing waves will exist. The correct termination of a concentric line



C1 - General Radio Type 334F Variable Condenser 500 mmf. maximum.

C2 - Same as C1.

C3 - Dubilier Type 9 Condenser, 250 mmf. Mount on terminal of unknown and run stiff self-supporting conductor from this condenser to D1. Avoid stray capacity between this condenser and other portions of the circuit.

D1 - Flexible braid not over 3 inches long with test clip. Run rigid self-supporting leads from R1 and from C3 to point where the clip may be transferred from one lead to another. Avoid stray capacity between these leads and other parts of circuit.

L1 - Single layer coil, 3 inch diameter, wound with #22 DCC wire:
For 550 to 1000 KC - 115 turns
For 1000 to 1500 KC - 52 turns

L2 - Single layer coil, 3 inch diameter, 10 turns #22 DCC wire. Coupling between L1 and L2 variable by changing separation between these coils.

M1 - Weston Model 425 Thermo-galvanometer.

R1 - General Radio type 602F Decade Resistance Box.

Fig.10 Impedance Measuring Equipment - Schematic.

is of importance as a mis-termination may result in flashovers due to excessive voltages at points along the line. The input impedance of the Antenna Coupling Unit can be measured by measuring equipment such as used to obtain antenna characteristics or by the simple equipment described as follows:

(B) Measurement of Resistance and Reactance at Radio-Frequency. The Antenna Coupling Unit in this transmitter is tuned by adjusting the circuit elements until the resistance and reactance measured across the transmission line terminals are correct. If no other impedance measuring equipment is available, a simple circuit for making these measurements is shown on Fig. 10.

This circuit consists essentially of a series resonant circuit with provision for introducing either the unknown impedance or a circuit whose resistance and reactance are the same as the unknown. When the values of this substitution circuit are correctly adjusted, switching from the unknown to the substitution circuit will not change the reading of the meter M1. The circuit has the advantage that since the meter is always used at the same scale deflection, any inaccuracy in the calibration of the meter does not affect results.

Power is introduced into the measuring circuit from coil L2, which is loosely coupled to L1. This coupling must remain fixed during all measurements. The transmitter operating at reduced power may be used as a source of power for these measurements. The second mesh of the final power amplifier need not be finally tuned nor need the efficiency of this stage be adjusted. *The R.F. Input Control R20A must be kept extremely low* or standing waves in *the transmission line will cause arc-overs which may damage the line.* Coupling between L1 and L2 should be quite loose at the start to avoid burning out the sensitive meter in the measuring circuit.

It is essential for successful measurements that all stray capacities between parts of D1 be kept low. A description of a suitable arrangement for this purpose is given in the list of apparatus on Fig. 10.

RESISTANCE MEASUREMENTS. To determine the resistance of the unknown;

1. Loosen the coupling between L1 and L2. Clip D1 on the lead from C3. Tune C1 for maximum reading on M1. Increase coupling between L1 and L2 until the meter reads between 80 and 100 divisions. Check C1 to make sure that reading is the maximum value. Note this meter reading.
2. Clip D1 on the lead to R1. Tune C2 for maximum current, reducing current if it is too high by increasing the resistance in R1. Do not change the coupling between L1 and L2 or the setting of C1. When C2 has been adjusted for maximum current, adjust R1 until the meter reading is the same as noted under Step 1.
3. Check conditions by clipping D1 first in one position and then in the other. The meter deflection should be the same in each position.

When the circuit has been adjusted in this manner, the resistance of the unknown impedance is the same as the resistance in R1.

REACTANCE MEASUREMENTS. To determine the reactance of the unknown:

1. Short-circuit the terminals of the unknown impedance. Clip D1 on the lead to C3 and adjust C1 for maximum current.
2. Clip D1 on the lead to R1 and, without changing C1 or coupling between L1 and L2, adjust C2 for maximum current. Mark this setting on the dial of C2.
3. Remove the short-circuit from the terminals of the unknown impedance and adjust the circuit the same as when measuring resistance. The reactance of the unknown is

the difference between the reactance of C2 at this setting and at the previously marked setting. If the capacity of C2 is greater than the capacity at the marked setting, the reactance of the unknown is inductive. If the capacity of C2 is less than the capacity at the marked setting, the reactance of the unknown is capacitive. When tuning the Antenna Coupling Unit, it is not necessary to know the reactance since the unit is tuned to have zero reactance. This can be accomplished by adjusting the reactance of the Antenna Coupling Unit (by varying L1E as described in the instructions for adjusting this unit) so that C2 will be maximum at the marked point on its dial.

(C) ADJUSTING ANTENNA COUPLING UNIT. Prior to adjusting the Antenna Coupling Unit, the reactance and resistance of the antenna should be measured. If the reactance of the antenna is positive, a series antenna condenser will be required to cancel this positive reactance. This condenser should be connected in circuit at the point shown on Fig. 6 and should have a reactance from 5 per cent to 25 per cent greater than the antenna reactance. The current rating at the carrier frequency of this condenser should be at least 1.5 times the full power antenna current to allow for modulation and should be shunted by a suitable static drain resistor.

The adjustment of the Antenna Coupling Unit is made with the antenna connected to the unit, the ground switch D5E open and the impedance measuring equipment connected between terminals No. 1 and No. 2 (Fig. 6) in place of the transmission line. The object of the adjustment is to obtain an impedance between these two terminals equal to the characteristic impedance of the line, 65 ohms resistance and zero reactance for the line recommended for use with this equipment.[1] The resistance component of the input impedance is controlled by the setting of the antenna coil L2E. The reactive component, which would otherwise be included in the transmission line coil L1E.

With all of coil L1E cut out of the circuit by means of its clips,[2] adjust the antenna coil L2E until the resistance as measured between terminals No. 1 and No. 2 is equal to the characteristic impedance of the transmission line; that is, 65 ohms, within ± 5%. Two values of inductance can usually be found to satisfy this condition, one at which the measured reactance is negative and one at which the measured reactance may be either positive or negative. Either of these adjustments is satisfactory for operation if the measured reactance is negative or zero. If the measured reactance is positive, the other adjustment may be found by increasing the inductance of the antenna loading coil L2E.

After this adjustment is completed, adjust the transmission line coil L1E until the measured reactance is zero. A slight re-

[1] The characteristic impedance of a line is determined by its dimensions. If a line of different dimensions from those of the line recommended is employed, the actual value of impedance should be used in the adjustment of this equipment instead of 65 ohms.

[2] For very low impedance antennas, the coupling unit is furnished with a condenser in series with L1E. The condenser should not be short-circuited for this first adjustment.

adjustment of the antenna coil L2E may be required to keep the resistance component within the limits of 65 ohms ±5%.

After this adjustment is complete, reconnect the transmission line and measure the impedance looking into the transmission line at the transmitter end. If the line has been properly terminated, the resistance as measured at the transmitter should not differ from the resistance measured at the Antenna Coupling Unit by more than 5% and the reactance measured at the transmitter should not be greater than 5% *of the resistance component.*

5. ADJUSTING POWER AMPLIFIER

(A) INPUT CIRCUIT. After the oscillator-modulator unit has been properly tuned (directions in Lesson 12, Unit 3), S3C (Fig. 2 and 9) should be operated by throwing D6F "Power Transfer" to the "Full Power" position. L10C and C19C (Fig. 2) should then be tuned to anti-resonance. The grid clips should be connected on V1C and V2C for this tuning. Anti-resonance is indicated by a minimum on M2A, in the oscillator-modulator unit. After this circuit has been tuned, the "Power Transfer" switch D6F should be operated several times, operating S3C and S4C alternately. The tuning of the second mesh of the oscillator-modulator unit should not be affected by this switching. Leave D6F in the "Full Power" position.

(B) NEUTRALIZATION OF THE POWER AMPLIFIER. This amplifier is neutralized by inserting a sensitive thermo-galvanometer in the output circuit and adjusting the neutralizing condensers for minimum deflection on this meter. The procedure is as follows:

1. Remove the clips from L5D (Fig. 3). Set the clips on L4D and L1D in accordance with the data in the table following.

Remove one lead from L4D and clip the neutralizing thermo-galvanometer M3D between this clip and the position on L4D at which the clip was originally located.

TABLE
PRELIMINARY TUNING DATA FOR OUTPUT CIRCUIT
OF POWER AMPLIFIER

FREQUENCY	L1D TURNS EACH SIDE	L5D TURNS
550 kc	18	24
750 kc	16	12
1000 kc	14	11
1250 kc	8	11
1500 kc	3	7

L4D - set clips at 4th turns from each end for initial adjustment.

For intermediate frequencies use intermediate number of turns.

Number of turns on each side of L1D (Fig. 3) should be the same for initial adjustment. The number of turns on one side may be increased and number of turns on other side decreased after circuit is tuned to improve balance in plate currents of V1C and V2C.

On both coils L1D and L5D, the links provided should be used to short-circuit the unused end turns if there are more than three unused turns on the end of the coil. These short circuiting links change the inductance of the coil and should always be in position during the tuning of the circuits.

The clips on L5D should be so adjusted that the turns used are approximately in the center of the coil.

2. Start the complete transmitter by throwing the "Master Control" switch D4F on the Control Unit to "Start". Leave the "High Voltage" switch D5C on Unit C (Fig. 2) in the "OFF" position, and throw "Emergency Tube Change Switch" D6C located inside of Unit C to "On" position. Apply plate voltage to the oscillator-modulator Unit, but *not to the Power Amplifier.*

CAUTION: Never apply plate voltage to the Power Amplifier while the neutralizing thermo-galvanometer is in circuit. Failure to observe this precaution may result in burning out the thermo-galvanometer.

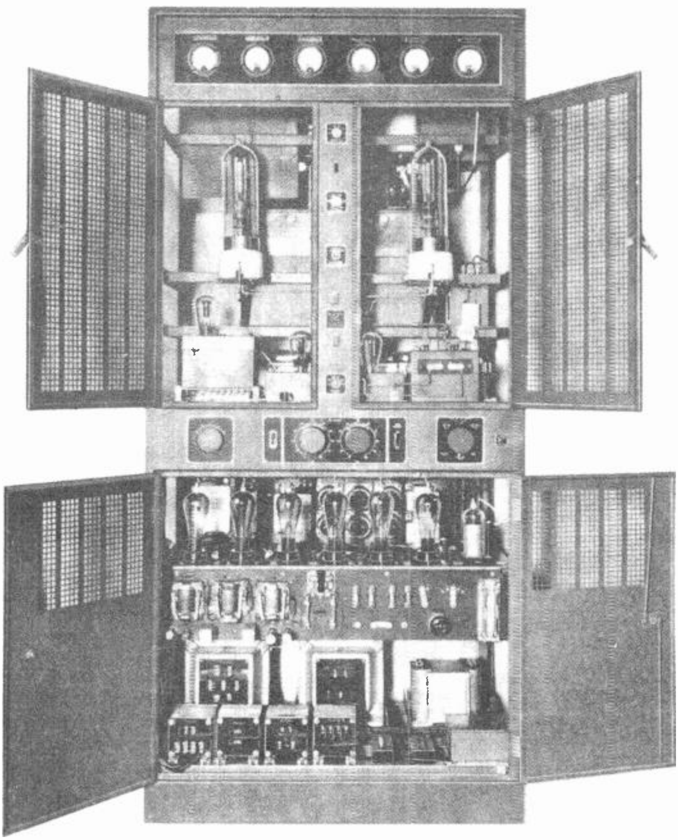


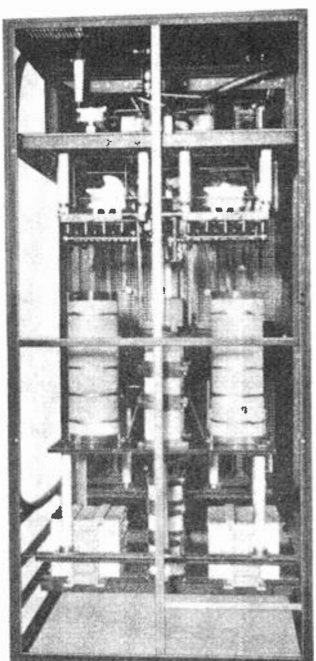
Fig.11 Open front view of Oscillator Modulator Unit showing assembly of the oscillator and modulator circuit apparatus with associated power supply equipment.

3. Increase the "R.F. Output" control R20A taking care not to exceed 150 milliamperes on the 3rd Amplifier Plate Current M4A or the maximum deflection of the thermo-galvanometer. Tune the output of the five kilowatt amplifier by means of the "Power Amplifier Tuning" control L1D until the deflection on the neutralizing thermo-galvanometer is maximum.

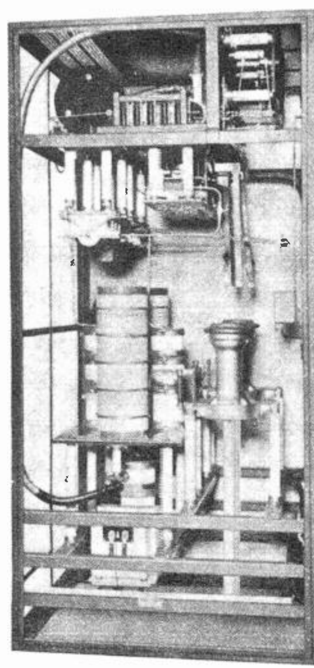
4. Turn the neutralizing control located on the center panel of Unit C by means of a screw-driver until the neutralizing thermo-galvanometer M3D reads minimum.

5. Remove plate voltage from Oscillator-Modulator Unit and disconnect the neutralizing thermo-galvanometer. The "Power Amplifier Control" switch D5F should not be opened at this time, as this would interrupt the heating of the filaments of the tubes in the High Voltage Rectifier Tube Unit and delay the tuning of the remainder of the circuit.

(C) TUNING OF THE OUTPUT CIRCUIT OF POWER AMPLIFIER. The output circuit of the power amplifier consists of two tuned meshes. The first mesh was approximately tuned during the process of neutra-



(A)



(B)

Fig.12 (A) Rear view of Power Amplifier Tube Unit. (B) Left side view of power amplifier Tube Unit showing sockets for the 220B Amplifier Tubes.

lizing, but due to the inductance of the leads of the thermo-galvanometer, some retuning will be necessary. These circuits are tuned as follows:

1. Open the second mesh by removing the clips from L5D (outer winding of the inter-mesh coupler in Fig. 3). Reduce the "R.F. Output" control R20A to zero.

2. Energize the complete equipment and apply plate voltage to all stages. Increase the "R.F. Output" control R20A until a readable deflection is obtained on the "Plate Current" meters M1C and M2C in Unit C. Tune the first mesh by means of the "Power Amplifier Tuning" control L1D for minimum reading on the "Power Amplifier Plate Current" meters M1C and M2C. Note the position of dial for this adjustment.

3. Remove plate voltage and place the clips on L5D as specified in table on Page 22.

4. Apply plate voltage and increase the "R.F. Output" control R20A until a readable deflection is again obtained on the "Power Amplifier Plate Current" meters M1C and M2C. Retune the first mesh for minimum reading on these meters and note how much the tuning differs from the previous setting.

5. The second mesh is correctly adjusted when the setting of the "Power Amplifier Tuning" control L1D for minimum "Power Amplifier Plate Current" is approximately the same when the clips are removed from L5D as when the clips are in position. If at the first setting of the clips on L5D this condition is not obtained, shift the position of these clips and compare the results with the results previously obtained. If the difference between the two settings of the "Power Amplifier Tuning" control L1D is less for the second position of the clips on L5D, change the position of the clips on L5D in the same direction until a satisfactory position on L5D is found. Conversely if the difference between the two settings of "Power Amplifier Tuning" control L1D is greater for the second position of the clips on L5D, change the clips on L5D in the opposite direction until a satisfactory position on L5D is found. Always place the clips on L5D in such positions that the active turns are approximately in the center of the coil. When the second mesh is properly tuned, the ratio of transmission line current to first mesh current will be a maximum.

As the object of the adjustment of the second mesh is to make this circuit series resonant, it is suggested that the adjustment may be quickly and easily made by an alternative method using the impedance measuring equipment described on Page 20. The transmission line is disconnected from terminal Nos. 34 and 35 on Unit D, Fig. 3. (These terminals are the lead - in bushings on the top of this unit) and the measuring equipment is connected across these terminals. The clips on the inner coil of the inter - mesh coupler L4D are disconnected and clips on L5D varied until the measured reactance is zero.

When the second mesh has once been tuned, it should not be changed during any further adjustment of the transmitter.

The coupling between the first and second mesh is adjusted by moving the clips on L4D. Increasing the number of turns in the circuit increases the resistance coupled into the first mesh and decreases the load impedance into which the amplifier tubes operate. Since the coil L4D is part of the first mesh, it is necessary to retune the first mesh (for minimum plate current) each time the coupling between the meshes is changed.

The initial adjustment should be made with approximately half the turns on L4D in the circuit. Check tuning of the first mesh and adjust the "R.F. Output" control R20A until five kilowatts is delivered to the antenna. Read the plate current and voltage of the last stage and compute the efficiency in accordance with the following expression:

$$\text{Per cent eff.} = \frac{(\text{Ant. Current})^2 \times \begin{array}{c}\text{Ant. resistance at}\\ \text{carrier freq.}\end{array}}{\begin{array}{c}\text{Total Plate Cur-}\\ \text{rent of Last Stage}\end{array} \times \begin{array}{c}\text{Plate Voltage}\\ \text{of Last Stage}\end{array}} \times 100$$

This efficiency should be approximately 25 per cent for minimum distortion of the modulated output. If the efficiency is too high, it may be lowered by increasing the coupling between the two meshes and conversely if it is too low, it may be increased by decreasing the coupling between meshes.

To some extent, the distortion contributed by the power amplifier to the modulated output is dependent upon the efficiency at which it operates. For the lowest distortion contribution, an efficiency of about 25% is employed and sufficient power is available from the High Voltage Rectifier for this adjustment. If it is required to operate at 33% efficiency, the distortion will be increased by a factor of about 1.75.

(D) FINAL ADJUSTMENT OF POWER AMPLIFIER INPUT CIRCUIT. With the Power Amplifier delivering 5 kw. note the reading of the Oscillator Modulator Plate Current Meter M4A. This reading will probably be somewhat less than the recommended value of 145 ±5 milliamperes. Reduce the values of both R7C and R8C in successive 1000 ohm steps until an adjustment is reached such that with the Power Amplifier delivering 5 kilowatts the plate current meter M4A reads 145 ±5 milliamperes.

(E) ADJUSTMENTS FOR REDUCED POWER OPERATION. After the transmitter has been adjusted for full power, the equipment should be adjusted for reduced power operation. With R20A "R.F. Output Control" at zero and R5F "P.A. Bias Rheostat" at about mid-scale, the "Power Transfer" switch D6F should be operated and the change in bias noted. Small adjustments of R21F and R23F (Fig. 9) may be necessary in order that the bias will change from 200 volts to 90 volts for some one setting of R5F.

With D6F "Power Transfer" in the "Full Power" position, R20A "R.F. Output Control" should be increased until 5 Kw. output is obtained. D6F should then be thrown to the "Reduced Power" position. Note whether R20A "R.F. Output Control" must be increased or decreased to obtain 1 Kw. output.

If R20A must be increased, then condensers C17C and C18C (Fig.

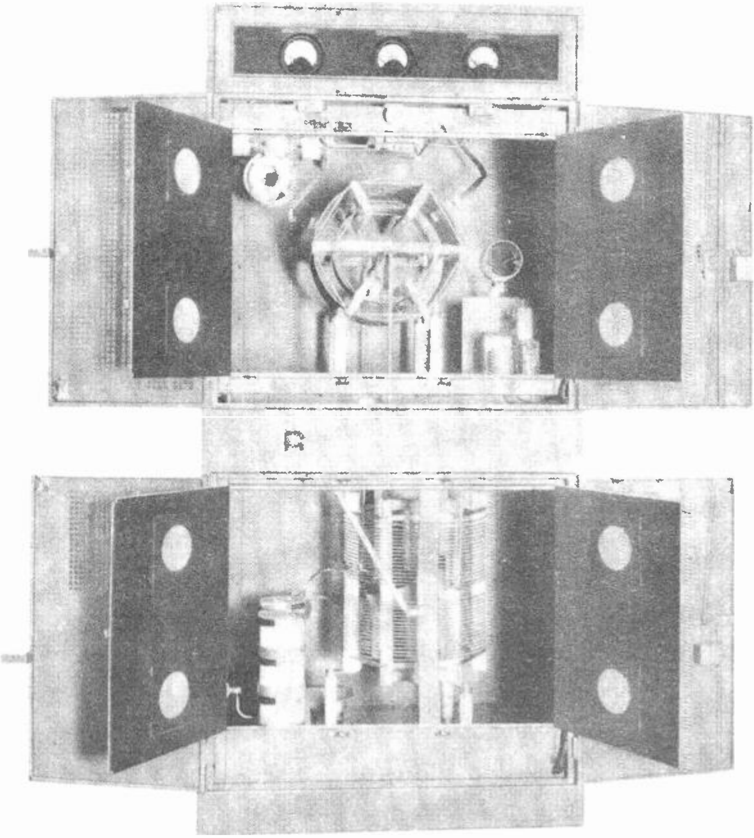


Fig.13 Power Amplifier Tuning Unit. Individual internal shields are employed, independent of the housing, for the power amplifier tank circuit in the upper compartment.

2) must each be decreased and by the same amount. If R20A must be decreased, then C17C and C18C must be increased. After any change of C17C and C18C, the Power Amplifier Tuning C18A must be slightly retuned for a minimum on M2A. The switching process is repeated and further adjustments made in C17C and C18C, until the output is properly reduced from 5 KW to 1 KW without a readjustment of R20A "R.F. Output Control".

(F) ADJUSTMENT OF FEEDBACK CIRCUIT. A tap is provided on L5D (Fig. 3) for obtaining the R.F. voltage for the feedback circuit. With this tap set for ½ turn and with R86A and R87A (on Osc. Mod. Unit in Lesson 12) set to zero adjust the primary of L37A until M1A indicates 15 milliamperes in the feedback circuit. The tap on L5D may have to be increased to obtain this current. This

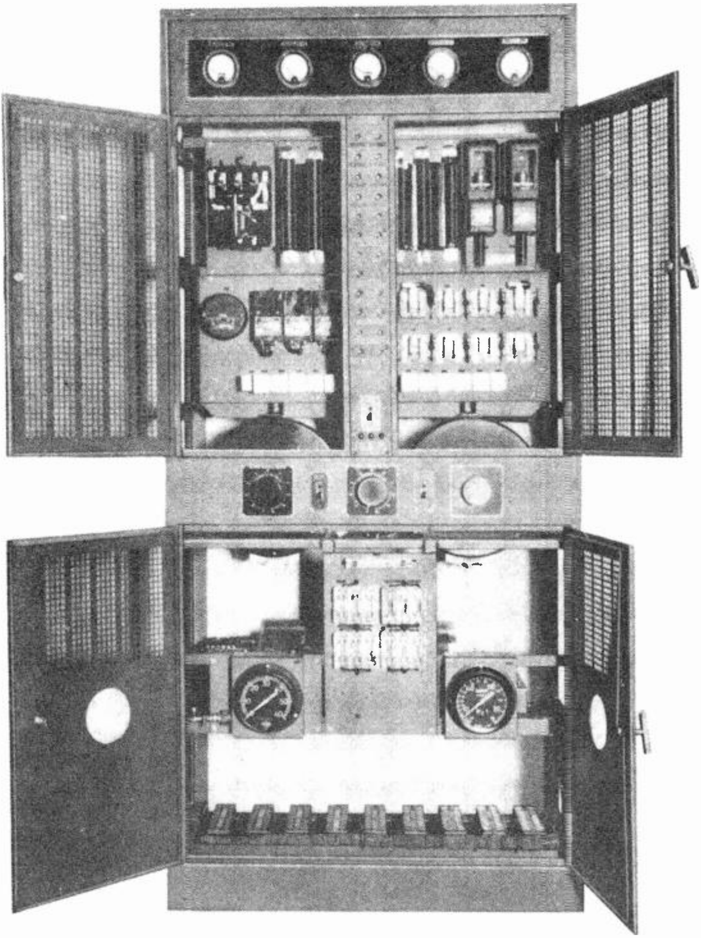


Fig.14 Control Unit with doors open.

current should be obtained with the transmitter operating at 5 kilowatts output. The audio input level to the transmitter for 100% modulation at 400 cycles should then be measured. R86A should be increased and a new reading of audio input level for 100% modulation obtained. The difference in audio levels for the two cases will be an indication of the amount of feedback. This will usually be about 20-25 db for this equipment. When this adjustment has been obtained, the "Power Transfer" switch D6F is thrown to the "Reduced Power" position so that the transmitter is delivering 1 kilowatt output. Without disturbing any of the previous adjustments, the transmitter is modulated by the same audio level as was determined previously with feedback. R87A is then adjusted until this same audio level will modulate the transmitter 100%. When these adjustments have been made, the same audio level will modulate the transmitter 100% at either 1 kilowatt or 5 kilowatts output.

When finally adjusted all meters on the equipment should be within the settings specified in the Table on Page 30. The exact readings of all meters should be recorded for use in maintaining the adjustment.

The Radio Transmitting Equipment is capable of operating with a low harmonic content, but this quality can be obtained only when the transmitter is carefully adjusted. The best adjustment can be obtained only if some method of quality checking is used during the final adjustment of the equipment. Such apparatus may consist of a cathode-ray oscillograph or preferably distortion measuring equipment. Best quality cannot be obtained at any arbitrary efficiency, and for best operation, quality and not efficiency should be the determining factor.

(G) ADJUSTMENT OF MONITOR CIRCUIT. The coupling between the pickup coil of the monitor and the transmitter is adjusted by rotating this pickup coil on its mountings. With the equipment operating at Reduced Power, the coupling should be increased until a setting is found at which the monitor rectifier delivers sufficient current to pull up relay S1D and light the "Power Amp. Monitor" lamp if relay S1D is correctly adjusted. The monitor will then deliver approximately zero level (6 milliwatts) into a 500 ohm load when the transmitter is fully modulated. Some adjustment of the monitor output level can be made by adjusting the tap on R3D,

(H) CALIBRATION OF ANTENNA CURRENT METER. Provision is made for reading the antenna current at the transmitter proper by the "Antenna Current" meter M4D on the Power Amplifier Tuning Unit and its associated thermocouple TC1E in the Antenna Coupling Unit. This thermocouple is inductively coupled to the antenna circuit to provide suitable voltage insulation. The actual current through TC1E for full scale deflection of M4D is less than the antenna current but by adjusting the coupling of T1E, full scale deflection on meter M4D is obtained with the same antenna current that gives full scale deflection on the antenna ammeter in the Antenna Coupling Unit.

Meter M4D has two ranges, one for 5 kw. operation and one for 1 kw. operation. These scales are changed automatically by relay S2D. It is important that the resistance leads, radio-frequency choke coils, etc., between TC1E and M4D be exactly 4.00 ohms so that the meter will read accurately on both scales. To adjust this circuit, remove the two meter wires from their terminals on TC1E and connect them together. Remove wires from terminals Nos. 1 and 3 on the "Antenna Current" meter M4D and connect these wires to a Wheatstone bridge. Unwind some of the resistance wire from the resistor R5D until the measured resistance is 4.00 ohms.

The thumb screw projecting from the top of the current transformer assembly is used to adjust the coupling between the primary and secondary of T1E, To calibrate the "Antenna Current" meter M4D, rotate this thumb screw until the reading on meter M4D is the same as the reading on the "Antenna Current - High Power" meter in the Antenna Coupling Unit. This calibration should be made at some current between 2/3 and full scale reading. Since the accuracy of this metering device can never be better than that of the meter used for calibration, if there is any question as to the accuracy of the "Antenna Current - High Power" meter it should first be checked against a suitable standard at 60 cycles.

TABLE - TYPICAL METER READINGS

UNIT A - OSCILLATOR-MODULATOR UNIT	1 KW OR 5 KW
Power Supply Voltage - M6A	220 ±5 V.
Oscillator Plate Current - M1A	6 - 12 Ma.
First Amplifier Plate Current - M1A	3 - 20 Ma.
Second Amplifier Plate Current - M1A	10 - 30 Ma.
Third Amplifier Plate Current - M4A	145 ±5 Ma.
Third Amplifier Output Current - M2A	0.4 - 1.2 Amp.
Third Amplifier Plate Voltage - M5A	3000 ± 100 V.
Oscillator Grid Current - M1A	.05 - 1.0 Ma.
Third Amplifier Grid - M1A	0
First A.F. Plate - M1A	7 ±2 Ma.
Second A.F. Plate - M1A	42 ±5 Ma.

	5 KW	1 KW
Feedback Current - M1A	15 Ma.	7.2 Ma.

UNIT C - POWER AMPLIFIER TUBE UNIT	5 KW	1 KW
Input Current - M3C	70 ±25 Ma.	70 ±25 Ma.
Plate Current Tube No. 1 - M1C	.85 ±.1 Amp.	.36 ± .05 Amp.
Plate Current Tube No. 2 - M2C	.85 ±.1 Amp.	.36 ±.05 Amp.

UNIT D - POWER AMPLIFIER TUNING UNIT	5 KW	1 KW
First Mesh Current - M1D	10-18 Amp.	4.5-8 Amp.
Transmission Line Current - M2D	8.78 ± .4 Amp.	3.92 ± .3 Amp.
Antenna Current - M4D	*	*

UNIT E - ANTENNA COUPLING UNIT	5 KW	1 KW
Antenna Current	*	*

UNIT F - CONTROL UNIT	5 KW	1 KW
Filament Voltage - M4F	Maintain at 22 Volts	
Rectifier Filament Voltage - M2F	Maintain at 200 Volts	
Bias Voltage - M3F	200 Volts	90 Volts
Plate Voltage - M5F	11.5 ± .5 Kv.	5.4 ± .3 Kv.
Leakage Current - M6F	10 Ma. max.	5 Ma. max.
Water Pressure - Q1F	Depends on local conditions	
Water Temperature - S13F	180° F. Maximum	

WATER SYSTEM	
Flow Meter - S5P	In white portion of scale.

6. OPERATING ROUTINE. After the transmitter has been adjusted, as described in the preceding sections, a regular operating procedure should be set up and rigidly observed. The routine given below is presented as a model, which may be altered slightly to conform to local conditions.

* Antenna Current is determined by the equation:

$$\text{Ant. Current in Amperes} = \sqrt{\frac{\text{Power Output in Watts}}{\text{Ant. Resistance at Carrier Freq. in Ohms}}}$$

In the Antenna Coupling Unit, the high or low range meter must be used depending on the power output. In the Tuning Unit transferring from high to low power automatically changes the antenna meter from high to low scale.

(A) STARTING PROCEDURE. Before attempting to start the transmitter, the operator should make a thorough inspection of the unit assemblies, power apparatus and pump room observing the condition of the conductors, the positions of switches, and particularly making certain that no person is inside of the high voltage rectifier enclosure.

In order to insure best operating conditions during the transmission of program signals, the transmitter should be started not later than thirty minutes before the station is scheduled to go on the air. This practice not only allows the component parts of the transmitter to rise to operating temperature, but provides time for the correction of trouble conditions. Experience has shown that many such conditions appear during the starting period, after the transmitter has been shut down for several hours. In addition, a thorough preheating of the filaments of the rectifier tubes before applying high voltage is beneficial to the operation of these tubes.

This transmitter may be started with either automatic or semi-automatic control. For automatic control, all plate voltage switches, the "Master Control" switch D9A on Unit A and the "Power Amp. Control" switch D5F on Unit F are put in the "On" position and the equipment started with the "Master Control" switch D4F on Unit F.

For semi-automatic control, all plate voltage switches are thrown to "Off" and the plate voltage applied to each stage in turn after filament and bias voltage has been applied by operating the "Master Control" switch D4F on Unit F.

While automatic starting puts the transmitter in operation with the least possible delay, it is sometimes advantageous when time permits to use semi-automatic control. If the room temperature is below normal, the transmitter should never be started automatically but before energizing the high voltage rectifier, the rectifier filaments should be carefully preheated until all mercury which may have condensed on the glass support above the anode of each 315A Vacuum Tube has been vaporized.

(B) AUDIO INPUT LEVEL. The quality of the output of the best adjusted transmitter will be poor if 100% modulation is consistently exceeded. To avoid over-modulating, the station should be provided with some device for measuring percentage of modulation. The per cent of modulation should be checked very frequently at the transmitter, and whenever overloading occurs repeatedly, the audio input to the equipment should be reduced.

Quality may also be checked by listening critically first to the input of the transmitter and then to the output of the monitoring rectifier using the same amplifier and loud speaker. The volume from the loud speaker should be adjusted, by means of the potentiometer provided for this purpose in the speech input equipment, to provide equal levels from each of the circuits. Both speech and music should be used in this comparison.

7. MAINTENANCE. For best operation, this equipment must be kept free from dust and dirt. High pressure air is recommended for cleaning, but a soft clean cloth may be used with good results. Waste or oily cloth should never be used.

Dirt and excess oil should be wiped off the power equipment with clean, soft dry cloths. The bearings of all rotating machines should be kept well lubricated at all times.

The insulating oil of the plate transformers and the filter retard coil should be inspected at regular intervals. For detailed information, see monthly maintenance schedule.

The water cooling system should be inspected at frequent intervals and any leaks should be carefully stopped. Care should be exercised to avoid any strains on porcelain pipes and porcelain coils. When porcelain pipe connections are being tightened or disconnected, apply wrench to metal fittings only - never to the porcelain itself. Never put twisting strain on porcelain pipes or coils.

The electrolysis targets shall be examined at regular intervals and shall be replaced when necessary to assure that they extend into the porcelain pipes or coils beyond the metal fittings.

The distilled water system should be drained and refilled with distilled water whenever the conductivity increases to the point where the leakage current, as read on meter M6F reaches 10 milliamperes.

If there is a sludge deposit in the water system it should be flushed out with clean water.

If the plate currents of the Power Amplifier tubes show an increase and the "R.F. Output" control R20A must be considerably increased after several months of operation, the resistance of the water column between the two tube jackets VS1C and VS2C should be measured with the DC plate supply leads removed. If this resistance is less than 150,000 ohms, the porcelain water coil connecting the tube sockets should be swabbed out. Temporary relief from such a condition can be obtained by decreasing the temperature of the water, if this is possible, but permanent relief can be secured by cleaning the water coil.

All nuts, bolts, screws and electrical connections should be examined occasionally and tightened if necessary.

Two or three times a year the antenna insulators should be cleaned thoroughly. This is especially important in locations where there is much smoke in the air, as soot will collect on the insulators, forming a leakage path which reduces the antenna efficiency.

8. MAINTENANCE SCHEDULE. In order that the 355E-1 Radio Transmitting Equipment may be maintained in the most efficient operating condition, the following maintenance routine is recommended.

(A) Daily Routine. After starting the pump, inspect the tube jackets and water connections for leaks.

(B) Weekly Routine. Oil the bearings of all rotating equipment. Keep the oil level up to the top of the oil drain outlets. After a long run, open the main power disconnect switch and feel the clip and hinge contact surfaces of all switches and fuses. If any of the parts are hot, the tension of the clips should be adjusted and the contact surfaces cleansed with fine sandpaper. Note the heater elements of the motor starting switches. If these are hot and the connected motor is cool, check the connection screws.

(C) Monthly Routine. Tighten all bolts, nuts and screws, particularly terminal strip nuts, flexible connections to the filaments of tubes, radio frequency coil connections, and bolts on the condensers in the tuning unit.

Clean contacts of magnetic switches by lightly filing or grinding down the contact surfaces.

Test samples of oil from the plate transformer and the filter retard coil for breakdown in accordance with the Standards of the American Society for Testing Materials. This test should be made before starting the amplifier for the first time and once a month for the first several months, in order to determine the rate at which the dielectric strength decreases. This will depend largely upon the humidity and the operating schedule. The frequency at which these tests are finally made will depend upon the rapidity with which the breakdown of the oil falls off, but should in no case be at intervals greater than three months. When the breakdown of the oil as determined by these tests falls below 22,500 volts r.m.s. the oil should be dried.

Bring the oil level in the oil-filled transformers up to the normal mark on the oil level gauge.

Clean the contacts of all control-circuit relay contacts with crocus cloth by drawing a narrow strip between the contacts, pressing the contacts together with the cloth between them.

Clean and polish the spark gap balls.

Wipe off all high voltage insulators with a clean dry cloth, particularly those in the Rectifier Tube Unit and the Power Amplifier Unit. Brush out any dust which may have accumulated in the interior of the Isolantite tubes supporting the tube mountings in the Rectifier Tube Unit.

Clean the water strainers on the inlet side of the pumps.

(D) Less Frequent Intervals. When required, repack pump stuffing box and motor bearings in accordance with pump manufacturer's specifications.

CHARACTERISTICS OF WESTERN ELECTRIC VACUUM TUBES.

TYPE TUBE	Normal filament current in amps. (H = Heater) (WC = Water Cooled)	Normal filament volts (H = Heater)	Plate current (ma.) normal unless marked M for maximum.	Normal plate voltage SG—screen grid	Safe plate voltage (max)	Normal grid voltage (M—max.)	Plate to filament impedance (ohms)	Amplification constant	Output (watts) M—max. continuous: MI—max. intermittent. A-B-C (Class)	Plate dissipation (max.) (watts)	Output as an oscillator (watts)
101-D	1.0	4.5	15	150	160	-15	6,500	6.5	0.230	...	...
101-F	0.5	4.1	M7.5	...	190	M-16	5,400	6.5	0.240	...	...
102-D	0.95	2.5	1.5	150	160	-3	100,000	34	.....	...	...
102-E	0.95	2.5	1.5	150	160	-3	100,000	34	.....	...	...
102-F	0.50	2.3	2.0	150	160	-3	100,000	33	.....	...	...
102-G	1.0	2.4	1.5	150	160	-3	100,000	34	.....	...	...
205-D	1.6	5.0	M30	350	350	-20	4,500	7.5	M-15 M-120	15	5
205-E	1.6	5.0	30	350	350	-30	4,500	7.5	M-15 M-120	...	..5
211-D	3.0	10.0	65	750	1,000	-30	4,000	13	M-65 MI-100	100	50
211-E	3.0	10.0	...	...	....	...	3,500	12	....	65	...
212-D	6.0	14.0	130	1,500	2,000	-60	2,000	17	M-200 MI-250	200	250
215-A	0.25	1.10	2.0	90	100	A-9	25,000	6.5	5	...	...
216-A	1.0	6.0	6.5	130	160	-9	5,900	5.9	.....	...	...
220-B	WC41	21.5 a.c. or d.c.	1,500	....	12,000	....	8,000	40	.....	10,000	...
228-A	WC41	21.5 a.c. or d.c.	1,500	....	6,000	....	2,000	16	.....	5,000	...
231-D	0.060	3.4 d.c	2.5	135	...	-7.5	14,600	7.8	.....	...	...
232-A	WC61	20 a.c. or d.c.	M3a.	....	20,000	....	7,000	40	.....	25,000	...
236-A	WC41	21.5 a.c. or d.c.	M2a.	....	20,000	....	8,000	40	.....	20,000	...
240-A	WC41	21.5 a.c. or d.c.	M1.7a.	....	12,000	....	9,000	40	.....	10,000	...
242-A	3.25	10.0	M150	1,000	1,250	A-50 B-100 C-150	3,500	12.5	M-100	100	M125
244-A	H1.6	H2.0 a.c. or d.c.	6.0	180	180	-10	10,000	9.7	.....	...	...
247-A	H1.6	H2.0 a.c. or d.c.	3.8	180	....	-7	16,000	14.6	.....	...	...
251-A	16.0	10-a.c.	600	....	3,000	....	2,250	10.3	.....	1,000	...
252-A	2.0	5.0	43 60	....	450 450	M-65 M-60	1,700 1,500	5.0 5.1	For fixed grid-bias. For self-biasing grid.		
254-A	3.25	5.0	60	....	750 SG175	....	80,000	80	.....	20 SG 5	...
254-B	3.25	7.5	M75	....	750 SG150	....	75,000	100	.....	25 SG 5	
256-A	H1.7	H2.3 a.c.	A triode, contains argon gas at low pressure. Intended for use in special circuits as relay or trigger-action device.								
259-A	H1.6	H2 a.c. or d.c.	7.5	180 SG 90M	....	-1.5	320,000	480	.....	...	...
261-A	3.25	10	72.5	1000	....	-50	3,500	12	.....	...	...
262-A	H0.32	H10 a.c. or d.c.	2.8	....	180	-7.5	17,500	14.[illegible]	.....	...	...
264-A	0.3	1.5 d.c.	2.6	....	100	-7.0	11,800	7.0	.....	...	...
268-A	3.25	5.0	...	....	....	....	5,000	5	....	30	...
270-A	9.75	10 a.c.	M375	....	3,000	A-150	1,750	16	.....	350	...
271-A	H2.0	H5.0 a.c. or d.c.	39	....	400	-30	2,850	6.5	.....	15	...
272-A	H0.32	H10 a.c. or d.c.	5.9	....	....	....	7,200	5.5	.....	...	...
275-A	1.2	5a.c. or d.c.	52	....	250	-60	1,000	2.8	.....	...	...
276-A	3.0	10 a.c.	M125	....	1,250	A-50 B-100 C-150	3,500	12	A 10 B100 C100	85 100 100	M100
277-A	H2	H5 a.c.	A triode, contains argon gas at low pressure. Intended for use in special circuits as relay or trigger-action device.								
279-A	H21	10 a.c.	800	....	3,000	-275	1,800	10	.....	1,200	...
282-A	3.0	10	M100	....	1,000 SG250	....	70,000	100	.....	70	...
284-A	3.25	10 a.c.	M150	....	1,250	....	1,900	4.7	A50 B-C-100	85 100	...
287-A	7.0	2.5 a.c. or d.c.	A triode, contains argon gas at low pressure. Intended for use in special circuits as relay or trigger-action device.								
305-A	3.0	10	M100	M1000	SG250	....	40,000	56	.....	60(SG5)	...

CHARACTERISTICS OF WESTERN ELECTRIC RECTIFIER TUBES

Type	Max. Peak Plate Current Amp.	Filament or Heater		Max. Peak Inverse Volts
		Volts A.C.	Current Amp.	
214-D & E	.200	10	D 3.0 E 3.25	2,000
**249-A	1.1	2.5	7.0	6,500
**249-B	1.5	2.5	7.5	7,500
**253-A	0.5	2.5	3.0	3,500
**255-A	5.0	5.0	21.0	20,000
**258-A	1.1	2.5	7.0	6,500
**258-B	1.5	2.5	7.5	7,500
††263-A	6.0	2.5	15.0	100
**263-B	10.0	2.5	15.0	100
**266-B	20.0	5.0	42.0	20,000
**267-B	2.5	5.0	6.75	7,500
†274-A	.200	5.0	2.0	1,800
**280-A	0.5	2.5	3.0	3,500
**†301-A	1.0	5.0	3.0	1,800
**†314-A	2.5	5.0	5.0	300
**315-A	2.5	5.0	10.0	12,500
**319-A	2.5	5.0	6.75	7,500
**321-A	2.5	5.0	10.0	12,500
*222-A	5.0	21.5	41.0	25,000
*233-A	5.0	21.5	41.0	50,000
*237-A	8.0	20.0	61.0	50,000

* Designates water-cooled plate.
** Designates mercury vapor type.
† Designates full wave.
†† Designates argon filled rectifier.

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