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LOW POWER RADIO TRANSMITTERS FOR BROADCASTING*

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Summary—*This paper discusses the place of low powered installations in the existing radio broadcast system, and the importance of apparatus for such stations meeting the present-day requirements pertaining to frequency stability, modulation capability, fidelity, and radio-frequency harmonics. The characteristics and more interesting features of a new line of transmitters covering the range of output from 100 to 1000 watts are described. The basic unit is a 100-watt transmitter employing grid-bias modulation which is novel in so far as American broadcast practice is concerned. Outputs of 250, 500, and 1000 watts are obtained through the use of a supplementary amplifier unit equipped with tubes of appropriate capacity. Radiation-cooled tubes are used throughout, and both units are self-contained, being operated direct from an alternating-current supply without the use of rotating machinery. Mechanically the units are novel in that the housings are of a cabinet form with doors which allow complete access from the front for adjustment and maintenance.*

Radio broadcasting began with the use of transmitters of what we would now term low power. That these were not ineffective is evidenced by the immediate response given by the public and the rapid growth of the new industry.

However, to extend the distances over which programs could be satisfactorily transmitted and to reach receiving points unfavorably located, the necessity for powers greater than the few hundred watts first employed was soon recognized and the development of equipment rated at five kilowatts and upward followed. This development has been characterized by important technical advances in equipment and paralleled by a great growth in the broadcast industry with its own important advances in technique. Not a little of the growth and increased effectiveness of broadcasting is due to the capabilities of this so-called high power equipment and its performance in rendering service not otherwise possible.

Recognition of what has been accomplished with relatively high powered transmitters, and of the fact that they offer the only satisfactory means of broadcasting over large areas, has tended to divert attention from low powered equipment and has possibly prevented a general appreciation of its capabilities in the field for which it is adapted, that is, in the serving of relatively small areas. The terms

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"low power" and "small area" are both indefinite, and while we may arbitrarily define "low power" as covering transmitters rated at one kilowatt or less, the "area" which one of these transmitters may be capable of serving cannot be defined in such an arbitrary manner as it is dependent upon many factors. Important among these are the class of service required, the nature of the territory over which the transmission takes place, and the receiving conditions encountered.[1]

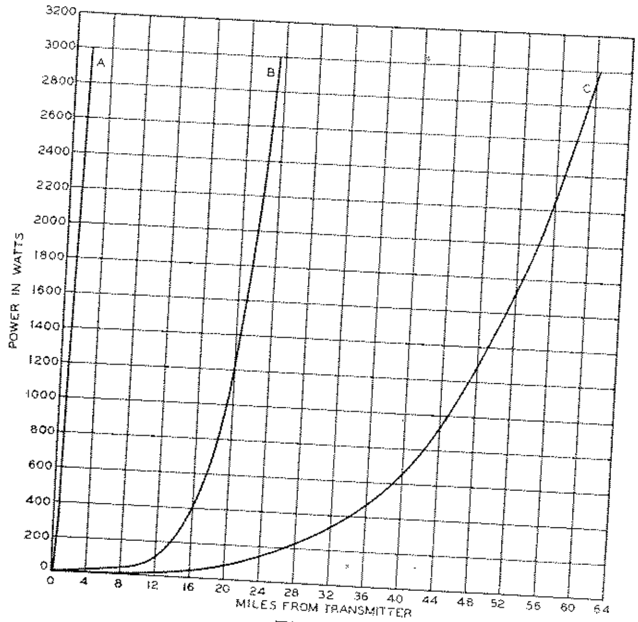

Fig. 1

Simply to indicate in a general way the comparative results which may be expected with the radiation of different amounts of power, there have been plotted on Fig. 1 a number of curves to show the distances from a broadcast station at which, under the conditions assumed, certain field strengths will be obtained. Three curves are shown. Curve *A* indicates the approximate distances at which the field strength is 200 millivolts per meter. Curves *B* and *C* indicate the approximate distances at which the field strength is 2 millivolts under unfavorable and favorable conditions of frequency and attenuation. It will be seen that with 100 watts radiated field strengths between 200 and 2 millivolts may be expected over distances between one-fourth

[1] C. M. Jansky, Jr. and S. L. Bailey, "On the use of field intensity measurements for the determination of broadcast station coverage," Proc. I.R.E., vol. 20, no. 1, pp. 62–76; January, (1932).

and 12 to 21 miles from the station, and with 3000 watts radiated the same range of field strengths may be had over distances between 2 and 24 to 60 miles.

While these curves and figures are only typical, they do illustrate the extent to which power must be increased to extend materially the region of high daytime field strengths and the effectiveness of small amounts of power in producing these field strengths over appreciable though relatively short distances. With full realization that the larger areas must of necessity be served with high power equipment, and that closely grouped smaller areas may well be taken care of in the same manner to advantage, it is evident that small isolated areas can be adequately served with rather small amounts of power. Thus where a program has only community interest and it is not desired to cover more than the local area, a single small station will probably do all that is required. Also, where it is wished to distribute a program to a number of limited areas around separate centers of population, the provision of a number of low power transmitters, one centrally located in each area, is an efficient and economical arrangement. In this connection, it may be noted that centrally locating small transmitters is not a serious problem as the points of very high field strength which might cause troublesome interference do not extend far from the transmitter. This feature is advantageous as it facilitates useful employment of the radiation in all directions from the transmitter location.

The importance which has been attached to the possibility of serving the smaller communities at relatively low cost through the use of low power equipment is indicated by the facts that nearly half of the total number of broadcast channels are given over to stations of one kilowatt and less in power, and that there are some 500 of these stations.

Compared with a larger station, the sphere of influence of one of these may be relatively small, and apparatus failure or irregularity at a single station may be relatively unimportant; nevertheless they represent in the aggregate a great many listeners who are entitled to receive satisfactory service. Poor service and poor quality are distasteful to the individual whether he is one of a few listeners or one of thousands.

For these reasons, regulations covering the performance of equipment as it affects the service given or the general broadcast scheme apply equally to transmitting equipment of all powers. As these regulations are made more rigorous to gain the advantages of progress in the art, increasing attention must be given to the equipment which is employed, and to the details of design which enable it to meet the exacting requirements placed upon it. In the case of low power equipment particularly it is important that both operation and maintenance of the high performance standards required be had at reasonable expense.

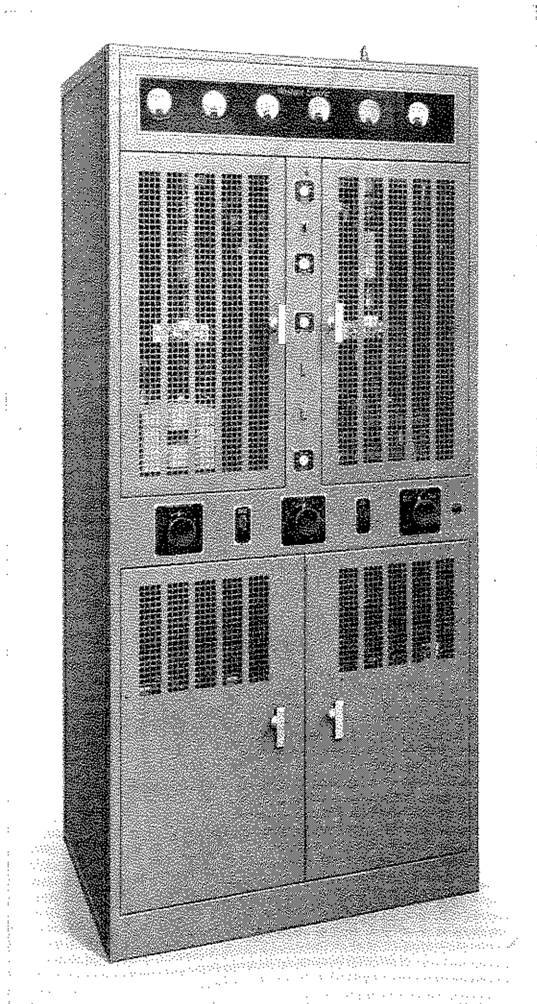

Fig. 2—Western Electric No. 12-A (100-watt) radio transmitter.

To illustrate how the various demands upon it are met in a modern radio broadcast transmitter, a line of low powered equipment will be described in which a number of novel features have been incorporated.

The basic unit is the self-contained 100-watt radio transmitter shown in Figs. 2 and 3. It occupies a floor space 36 by 25 inches and stands 6 feet 6 inches high. The housing marks a departure from what

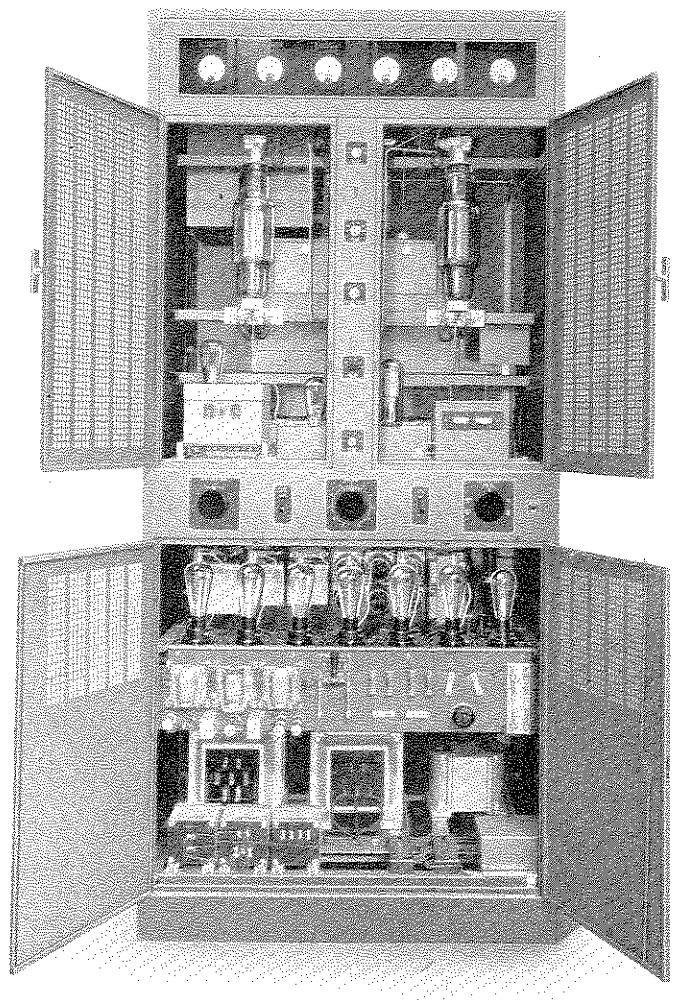

Fig. 3—Western Electric No. 12-A (100-watt) radio transmitter (doors open).

has been common in this type of equipment. It is in the form of a substantial steel cabinet designed and finished to present a pleasing appearance. The meters and controls are conveniently grouped to allow large doors in the front which permit access for all ordinary adjustment and maintenance.

The circuit of this unit, somewhat simplified, is shown in Fig. 4. The quartz controlled oscillator at the left provides frequency stability well within the present 50-cycle requirement with practically no maintenance. No adjustment of thermostat or circuit is required of the operator, and as the crystal is not handled after calibration, the fre-

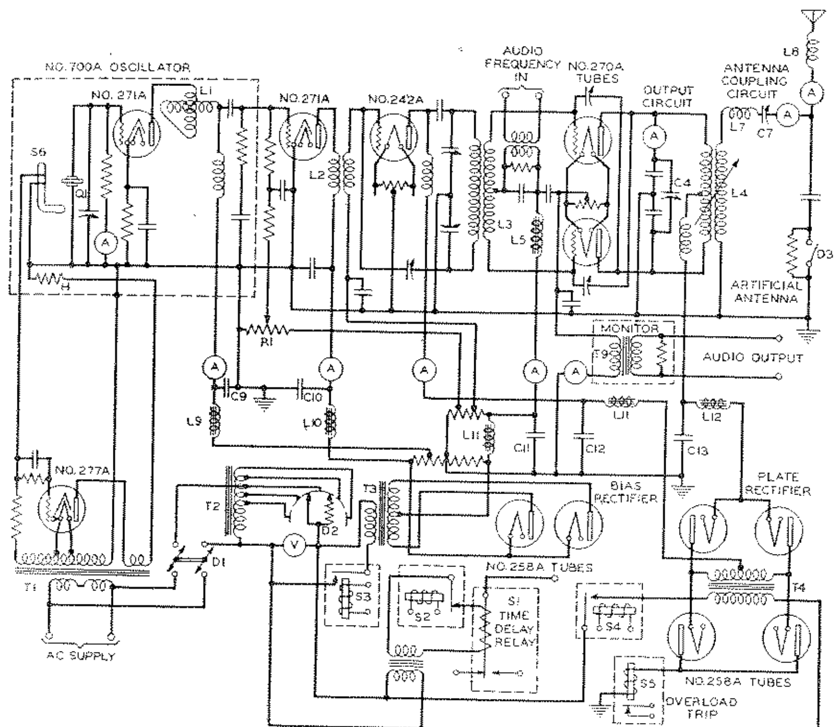

Fig. 4—Simplified circuit of the No. 12-A (100-watt) radio transmitter.

quency control may be said to be truly automatic, and the hazards of careless handling or maintenance are minimized. The entire oscillator circuit is housed and calibrated as a unit which may be readily removed or replaced in the transmitter. Fig. 5 shows how this oscillator unit is placed in position in the transmitter. The control element in the crystal heater circuit is a three-element gaseous tube rectifier. When the contact in the thermostat is open, this rectifier is allowed to pass current to the heater as the grid of the tube is effectively positive in respect to the filament. When the correct operating temperature is reached and the contacts of the thermostat close, the grid of the tube is connected in such a way that it is always out of phase with the plate voltage, and no current can flow through the tube into the heater. This method of heat control eliminates the usual relay and reduces the

Fig. 5—Placing crystal oscillator unit in the transmitter.

amount of current that the thermostat contact is required to carry to a negligible amount.

The second tube is of the same type as the oscillator and is resistance coupled to it. Grid bias is obtained from a potentiometer and transmitter as the output of this buffer tube is smoothly varied from nothing to full output by merely changing the bias from a value so far beyond cut-off that no output is obtained to a value that will give the desired output.

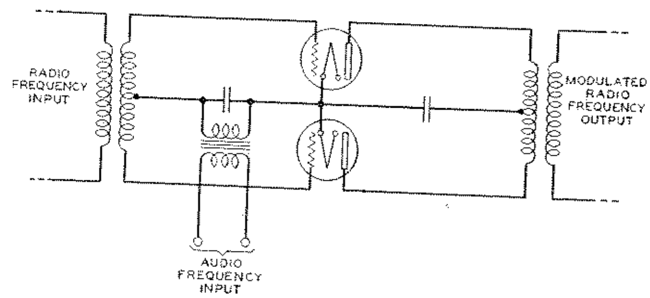

Fig. 6

This stage is transformer coupled to the second stage which in turn is coupled to the final stage by means of a tuned circuit and neutralized by the conventional Rice circuit.

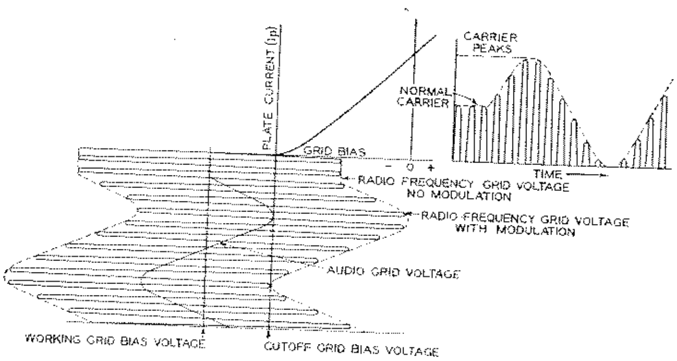

Fig. 7

The final amplifier stage employs two tubes in a push-pull circuit and it is here that modulation takes place. It is effected by what is known as grid-bias modulation. While it is believed to be entirely new to radio broadcasting, this type of modulation has been used in commercial carrier telephone systems for a number of years and is by no means untried. The type of modulation most desirable for a particular purpose is dependent upon a great many factors. The type employed in this transmitter is advantageous here in involving a minimum number of vacuum tubes, and in contributing to the simplicity and economy of operation. The fundamental circuit and the mechanism of its operation are illustrated in Figs. 6 and 7. The grids of the tubes are biased to considerably below cut-off, and the radio-frequency grid voltage is applied to the two grids out of phase as in any push-pull amplifier. The audio frequency or modulating voltage is applied to the two grids in parallel effectively in series with the grid biasing voltage. Thus the effective grid-bias voltage is varied in accordance with the audio frequency or other modulating voltage which accounts for the name "grid-bias modulation." Referring to Fig. 7, the direct grid-bias voltage is shown adjusted to approximately one and one-half times the value required to reduce the plate current to zero, and to this is added the radio-frequency input voltage sufficient to produce a radio-frequency output. If by changing the bias or otherwise the peak radio-frequency grid voltage is varied between cut-off, where no output is had, and some greater value, a completely modulated radio-frequency output is obtained. This transmitter is arranged so that when enough radio-frequency voltage is applied to the grids to just reach the point where they become positive, causing grid current to flow, the output is something over 400 watts which is the peak required for complete symmetrical modulation of 100 watts. The output is adjusted to 100 watts of carrier by adjusting the output of the first amplifier stage. The audio frequency, applied to the grids in parallel, is then adjusted so that the maximum swings of it, which are to effect complete modulation, cause the radio-frequency grid voltage to vary between cut-off and the point near where the grids become positive and the output is about 400 watts. As the tubes are operated so that the relation between input and output voltages is essentially linear, the audio-frequency distortion experienced is slight as is indicated by Fig. 8.

It will be noted that the transmitter contains no speech amplifier as the input transformer which connects to the grids of the modulating amplifier is fed directly from the speech input equipment. This is another step in separating the radio- and audio-frequency circuits in a radio broadcast system, a trend which began with the inauguration of low level modulation. The speech level required is +10 decibels, a value considerably higher than commonly required at the input of a radio transmitter, but one that any amplifier capable of operating a loud speaker can supply.

The output of the final and modulating stage is transferred through the output and antenna coupling circuits to the antenna. The coupling circuit, which includes the secondary of the output transformer L_4, the inductance L_7, condenser C_7, and the antenna coupling condenser C_8 is arranged to be very effective in the suppression of the radio-frequency harmonics. This simple network is not difficult to adjust, and increases in effectiveness with the order of the harmonics. L_7 is made so that its reactance is high at the fundamental frequency, and the circuit is tuned by adjustment of C_7. As the antenna coupling reactance is relatively small, the reactance of L_7 is practically annulled by the negative reactance of C_7, so that for the fundamental frequency the reactance of L_7 and C_7 together is very small. At harmonic frequencies the reactance of L_7 increases while that of C_7 decreases, and the resultant reactance of the combination is relatively very large, thereby greatly discrimi-

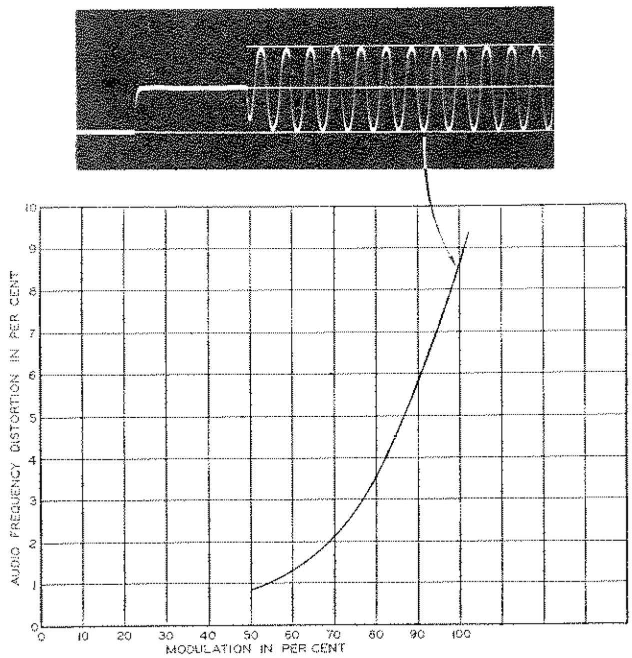

Fig. 8—Oscillogram of rectified output of the No. 12-A radio transmitter at 100 per cent modulation, and curve showing variation in audio-frequency distortion with percentage modulation.

nating against harmonic currents. Further discrimination is had by the effect of the negative reactance of the antenna coupling condenser. By the means employed, the harmonic radiation is kept well below 0.05 per cent of the fundamental, thus anticipating any requirement which may reasonably be expected.

The antenna is tuned by adjusting the antenna loading inductance L_8 for maximum current in the usual manner. An artificial antenna resistance is provided so that the transmitter may be energized without radiating a signal, should this be desired for test purposes.

A monitoring output is provided by means of a transformer which is connected in the plate circuit of the final stage. This type of monitor is new and does not require a tube or other type of rectifier. It is obvi-

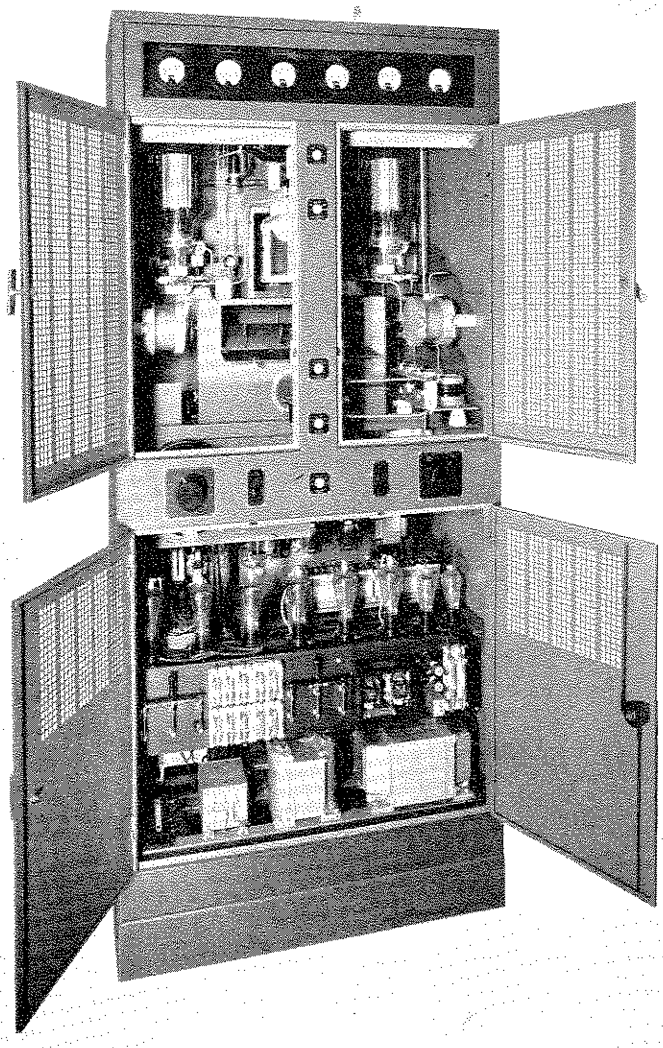

Fig. 9—Western Electric No. 71-A amplifier equipped for 1000-watt operation.

ous that the audio-frequency currents flowing in this circuit result from the modulation of the output of the amplifier, and therefore give a faithful indication of it.

The entire power for the transmitter is obtained from alternating-current supply without the use of rotating machinery. Two rectifiers supply 3000 volts for the last stage and lower voltages for plate and grid-bias circuits. Wherever voltage reduction is required, potentiometers are employed in order to provide stability of the derived voltage.

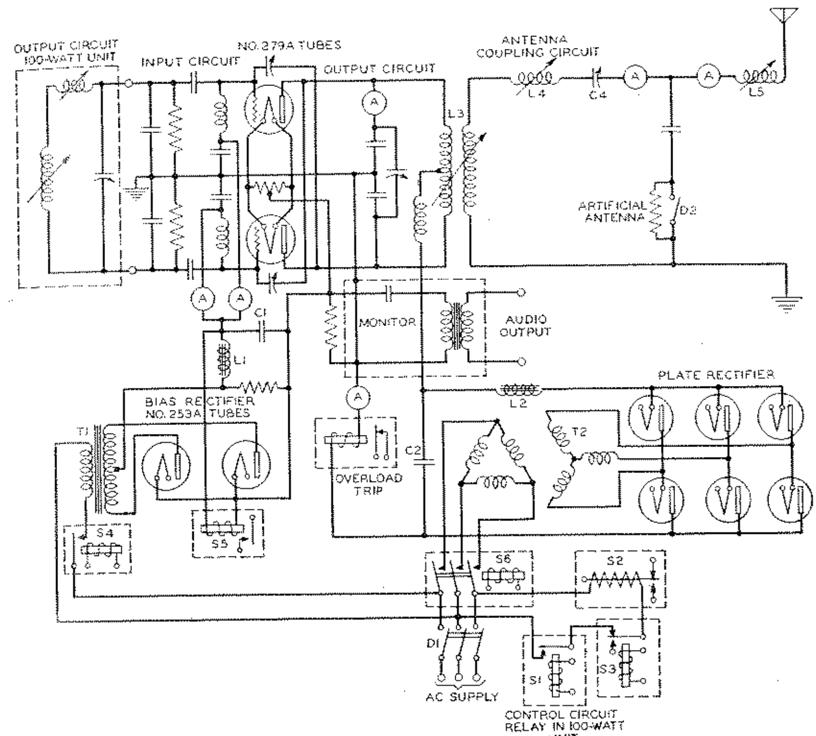

Fig. 10—Simplified circuit of the No. 71-A amplifier.

The circuits are controlled simply, and relays are provided to introduce the time delays necessary in energizing the mercury-vapor rectifier tubes. When the "START" switch is operated, closing D_1, the filaments are all lighted, and thermal relay S_1 begins to operate closing its front contacts after the proper interval. This operates the relay S_3 which locks itself up and, in addition to starting the low voltage rectifier that supplies all grid potentials and low plate voltages, operates relay S_2 opening the circuit through the thermal relay. This allows the relay to cool and remake its back contact which through S_4, operated by the grid-bias rectifier, energizes the 3000-volt rectifier. This sequence allows the rectifiers to come into operation properly and prevents application of plate voltage without grid bias. The overload relay in the high voltage rectifier operates to remove only the high voltage.

The power required for operation of the transmitter is approximately 1500 watts single phase.

The amplifier which is attached to the 100-watt unit to provide outputs of 250, 500, or 1000 watts is similar in appearance to the transmitter and occupies the same amount of space. It is designed for readily mounting the tubes required for any of the three-powers. It

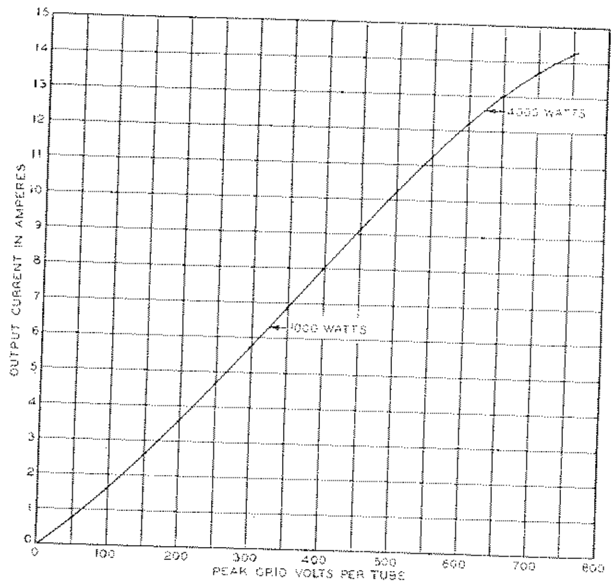

Fig. 11—Dynamic characteristics of the No. 71-A (1000-watt) amplifier.

also is a self-contained unit and operates directly from a three-phase alternating-current power supply. Fig. 9 is a view, with the doors open, of this unit equipped for 1000 watts output. It will be noted that all circuit elements likely to radiate are completely shielded. The box in the center contains the output circuit coupling coil, and the antenna loading coil is directly above it. The interior is divided horizontally into two main divisions with the power apparatus located in the lower section and the radio-frequency apparatus above.

A simplified circuit of the amplifier is shown in Fig. 10.

The amplifier input is connected to the terminals of condenser C_7 in the 100-watt unit. The resistances connected from grid to grid form the load for the driving unit and in them is dissipated the power output of the modulated stage. The remainder of the circuit is similar to that of the 100-watt unit with the natural exception that the circuit elements are designed for the larger currents they must carry. Here

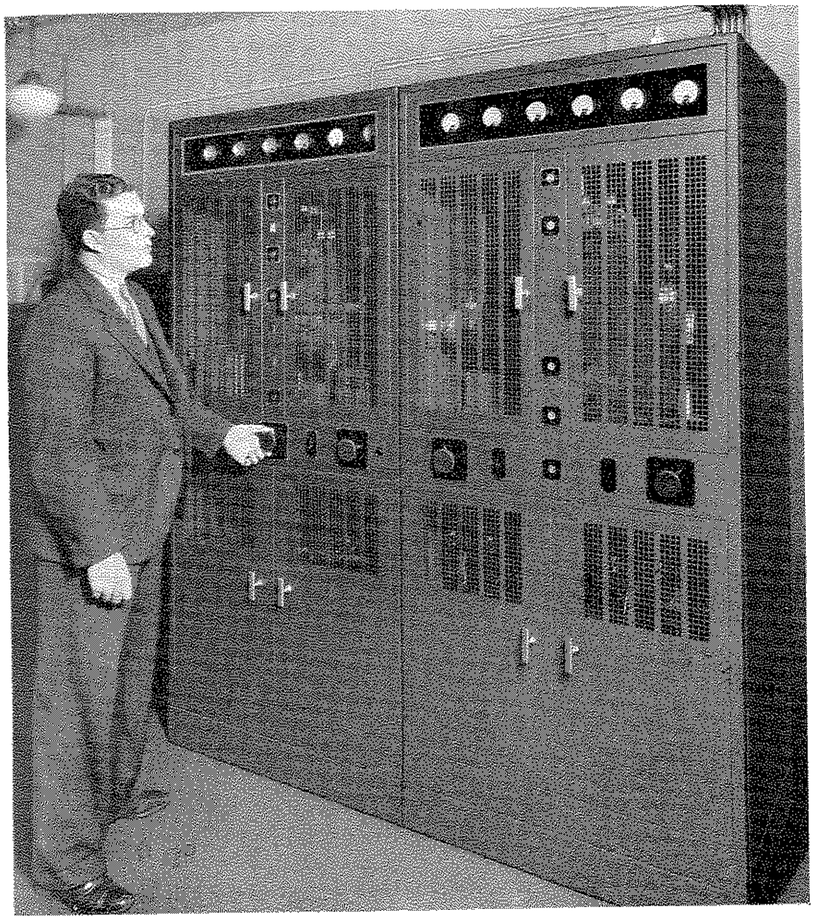

Fig. 12—Western Electric No. 304-A (1000-watt) radio transmitting equipment consisting of the No. 12-A radio transmitter and the No. 71-A amplifier.

again it will be seen that an artificial antenna resistance is provided to enable the transmitter to be operated for test purposes without radiating, and a monitoring arrangement similar to that in the 100-watt unit is provided.

Two radiation-cooled tubes of a new design are employed in a push-pull circuit. The dynamic characteristic of the amplifier shown in Fig. 11 indicates ample tube capacity to permit 1000-watt operation with complete modulation which entails a peak power of four kilowatts.

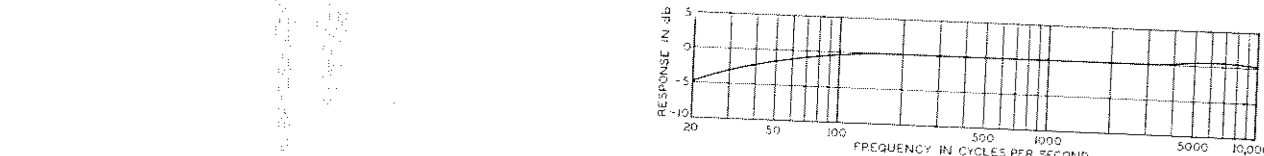

Fig. 13—Audio-frequency characteristic of the No. 304-A (1000-watt) radio transmitting equipment.

This unit requires about 4000 watts of three-phase power. The bias voltage is obtained from a full-wave single-phase rectifier which employs mercury-vapor tubes, and the 3000-volt plate potential is ob-

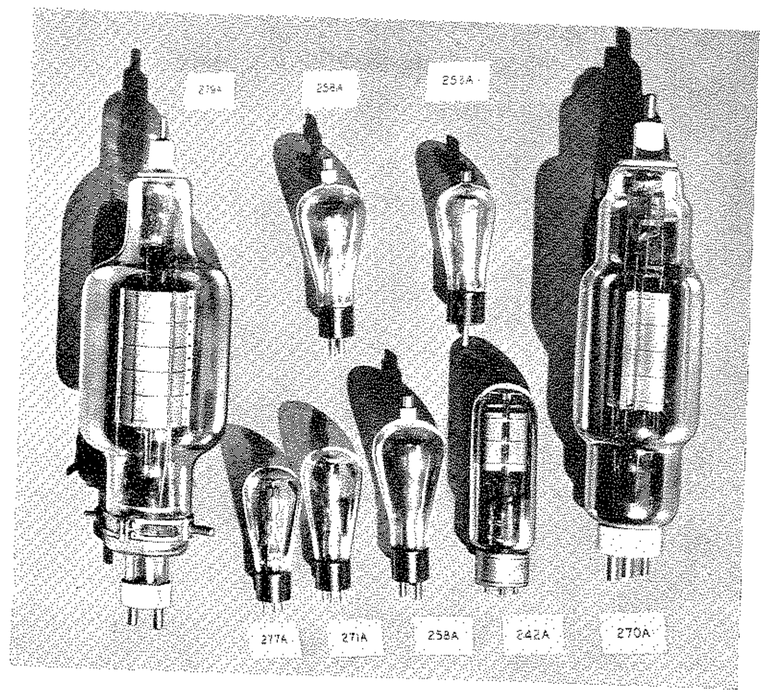

Fig. 14—Types of tubes employed in the No. 304-A (1000-watt) radio transmitting equipment (designations are Western Electric code numbers).

tained from a full-wave three-phase rectifier also employing mercury-vapor rectifier tubes. A thermal delay circuit provides the necessary time interval for the filaments of the tubes to reach operating temperature before the high voltage is applied. An overload trip is provided to prevent operation at heavy overloads, and a relay in the grid-bias circuit is used to control the application of high voltage, thus preventing the operation of the amplifier tubes without grid bias.

Fig. 12 is a photograph of a complete 1000-watt radio transmitter made up of the 100-watt unit and the amplifier just described. The entire equipment stands 6 feet 6 inches high and occupies a floor space 72 by 25 inches. All apparatus is accessible from the front for maintenance and adjustment. The sides and back panels are, however, readily removable should occasion require it. All of the meters are mounted under glass at the top of the units, and the controls are of the spanner wrench type, a feature that will be appreciated by those who may have had an adjustment changed by some curious visitor to the transmitter room.

The safety and control circuits of the two units are interlocked. Opening any one of the doors on either unit removes all high voltages from both units. While switches are provided so that starting may be sectionalized if desired, the entire transmitter may be controlled by the master switch in the 100-watt unit. When this switch is operated, all of the various circuits are energized in proper sequence, and the transmitter may be put "on the air" from a cold condition in less than a minute.

The audio-frequency characteristic of a complete 1000-watt transmitter is shown on Fig. 13.

Fig. 14 is a photograph of the various types of tubes used in the 1000-watt transmitter. The 271-A, 242-A, and 270-A are employed in the radio-frequency circuits of the 100-watt unit. The 258-A tube is used in the rectifier, and the 277-A controls the temperature of the quartz oscillator. The 1000-watt amplifier employs the 253-A and 258-A rectifier tubes and the 279-A amplifier tube.