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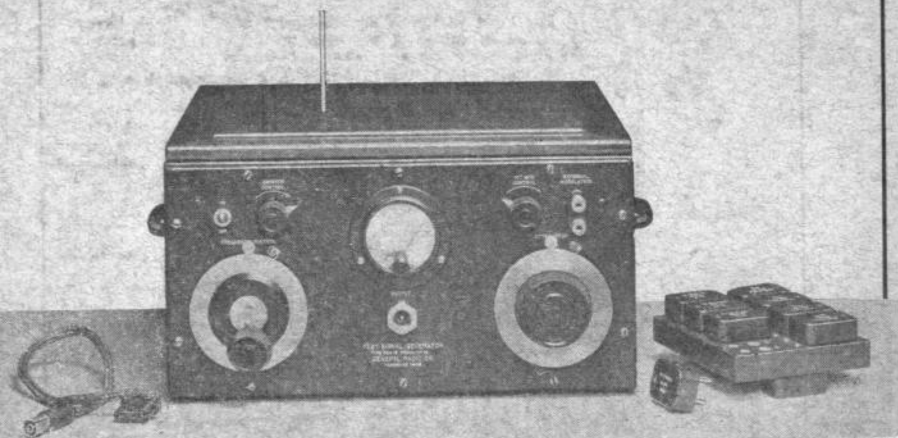

The Type 604-B Test-Signal Generator serves as a dependable measuring stick for receiver developments in this frequency range. A wide modulation frequency range provides for measurement of receivers intended for wide range television reception. Adaptability of output system, wide frequency and voltage ranges, and portability combine to make this generator a valuable addition to the receiver development laboratory.

SPECIFICATIONS:

- Frequency range: 3 megacycles to 100 megacycles
- Output voltage:
  - Attenuator: 5 microvolts to 10,000 microvolts
  - Antenna: 1 volt
- Price: $300.00.

Described in Bulletin 332-R

GENERAL RADIO COMPANY
CAMBRIDGE MASSACHUSETTS

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Engineering

VOLUME 22 OCTOBER, 1934 NUMBER 10

PROCEEDINGS
of
The Institute of Radio Engineers

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PROCEEDINGS OF

The Institute of Radio Engineers

Volume 22 October, 1934 Number 10

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Personal Mention

K. B. Austin of the General Electric Company has been transferred from Schenectady to Bridgeport.

C. R. Barhydt also has been transferred from Schenectady to the Bridgeport branch of the General Electric Company.

L. D. Boji of General Household Utilities Company is now at Marion, Ind. having formerly been at the Chicago, Ill., plant.

Previously with Hygrade Sylvania Corporation, W. J. Cahill has joined the staff of Naval Research Laboratory at Bellevue, Anacostia, D. C.

Formerly with Lincoln Export Company, R. H. dePasquale has formed an export company under the title Technical Products International in New York City.

Previously doing graduate work at Massachusetts Institute of Technology, C. W. Frank has joined the Associated Electric Laboratories of Chicago.

V. F. Greaves has been transferred from Washington to become chief inspector of the San Francisco office of the Federal Communications Commission.

Previously with Mullard Radio Valve Company, D. L. Hall has joined the staff of Cosmos Lamp Works, Ltd., of Brimsdown, Middlesex, England.

Guy Hill, Captain, U.S.A., has been transferred from Fort Monmouth to Patterson Field, Fairfield, Ohio.

J. H. Hinemon, Jr., Major, U.S.A., has been transferred to the War Department in Washington, D. C., from Fort Monmouth.

A. H. Hodge formerly with the Bureau of Standards has become a physicist at the Aberdeen Proving Ground, Aberdeen, Md.

I. J. Kaar has been transferred from Schenectady to the Bridgeport plant of the General Electric Company.

G. W. Kenrick of Tufts College, Mass., has joined the faculty of the University of Puerto Rico at Rio Piedras, P.R.

C. G. Lacombe previously with Companhia Radio Internacional do Brasil has become technical director of Radio Cinephone Brasiliera, S.A. at Rio de Janeiro.

Formerly with George Brown and Company, J. C. Miller has established Millers Wireless in Edinburgh, Scotland.

M. C. Partello, Lieutenant Commander, U.S.N., has been transferred from the Philippine Islands to commanding officer of the U.S.S. Biddle basing at San Diego, Calif.

Proceedings of the Institute of Radio Engineers
Volume 22, Number 10 October, 1934

TECHNICAL PAPERS

THE WLW 500-KILOWATT BROADCAST TRANSMITTER*

Summary—*In this paper the design, installation and, performance of the highest power broadcast station at present in America is described.*

Considerations underlying WLW's decision to increase power are mentioned. The station is unique in a number of respects, the most outstanding being the high level class B modulator producing audio-frequency outputs of 350 kilowatts, the "isolation" operation of the control circuit, and the concentric transmission line.

The vertical radiator is pictured and data are presented comparing its performance to that of a standard T antenna immediately adjacent. The more important performance characteristics of the transmitter and antenna are given.

Initial Considerations

THE 500-kilowatt broadcast transmitter at Station WLW in Cincinnati was placed in regular operation on May 2, 1934. This transmitter is of considerable interest to engineers, not because of the high power alone, but also because of the many unusual circuit and control devices incorporated.

WLW has consistently maintained its position as one of the most powerful broadcast stations in the United States, having been the first commercial broadcast station to utilize successive stages of increased power. It therefore is not surprising that this station, owned and operated by the Crosley Radio Corporation, is the first in this country to install a 500-kilowatt transmitter. Increased power is the most effective "static eliminator" yet devised.

The continuous improvement of transmitter and receiver design, with much improved receiver selectivity, has materially reduced adjacent channel interference. In addition, radio listeners have gradually

* Decimal classification: R612.1. Original manuscript received by the Institute, June 25, 1934. Presented before Ninth Annual Convention, Philadelphia, Pa., May 28, 1934.

Note: This paper was prepared by J. A. Chambers, Crosley Radio Corporation, in coöperation with L. F. Jones, RCA Victor Company, Inc., who prepared the sections devoted to the general engineering features and performance of the equipment; G. W. Fyler, General Electric Company, who described the radio-frequency power amplifier and antenna coupling system; R. H. Williamson, of the General Electric Company, who described the main rectifier and control circuits; E. A. Leach, of the General Electric Company, who prepared the section describing the physical layout; and J. A. Hutcheson, Westinghouse Electric and Manufacturing Company, who described the audio amplifier and modulator, as well as the cooling system and rotating equipment.

but surely changed their standards so that they now desire the high quality signal of considerable intensity in preference to their previous desire to hear stations on every channel irrespective of distance and quality. With present receivers, increased power is capable of improving the service rendered without creating appreciable interference. Furthermore, with the general use of automatic volume control in receiving sets, increased power of the broadcast station reduces fading in cases where the signal would otherwise fade below the noise level.

WLW, located near the center of population of the United States, endeavored to supply broadcast service to the millions of listeners located in rural communities and small cities, listeners who were at such distances from high quality broadcast stations that "secondary coverage" must be relied upon. In accordance with this endeavor, the WLW program policy of the last several years has been designed to serve a scattered audience rather than a highly concentrated audience.

It is assured that the service rendered by the use of 500 kilowatts will, in the case of WLW, justify its commercial operation. It is realized that the major audience increase will be in the secondary coverage area.

Preliminary plans to install a 500-kilowatt transmitter were started nearly four years ago. It was felt that 500 kilowatts was the next logical step above 50 kilowatts as any lesser increment of power would have shown relatively small improvement, whereas a greater increment would have involved large technical and economic risks. In May, 1932, the Crosley Radio Corporation application was filed with the Federal Radio Commission for a 500-kilowatt construction permit and was granted in the following month. The 50-kilowatt transmitter was to be retained as an exciter for the 500-kilowatt amplifier, with a means for switching from 50 to 500 kilowatts.

The total cost of the installation, including the equipment, the necessary addition to the building and the installation expense, but excluding the already existent 50-kilowatt exciter and the building housing it and studios or studio equipment, was approximately $500,000. It is expected that the annual cost of material operation, including tube replacement, power cooling water, etc., will be $170,000. This is based on twenty hours of operation daily. This figure does not include engineering personnel, depreciation and insurance, or any expenses related to studios or studio operation. The use of class B high level modulation resulted in a power saving of approximately $25,000 annually as compared to a radio-frequency linear amplifier. The yearly operation cost of $170,000 corresponds to approximately $23.00 per hour, which is obviously quite low as compared with the over-all operating expenses of the station.

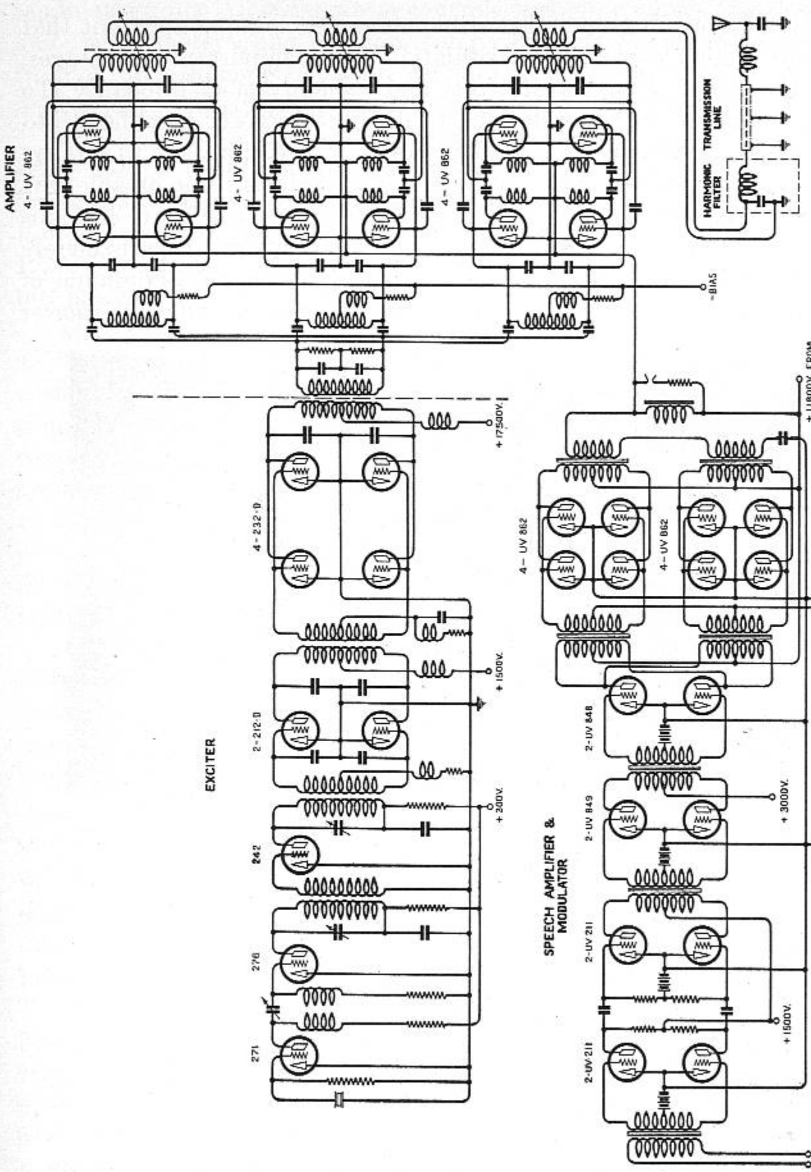

Fig. 1—Simplified schematic diagram.

General Design

After analyzing several possible circuits it became apparent that the use of high level class B modulation offered important advantages, particularly economy of first cost and economy of maintenance. To insure reliability, it was decided to divide the power amplifiers into three units and to divide the modulators into two units, and to arrange for the automatic isolation of any unit in which a tube or any part becomes defective. (See Fig. 1.) The result is that a defect in a modulator or a power amplifier, regardless of whether this defect is merely a burned-out tube or something more serious, causes a minimum of interference with the program. Each modulator and each power

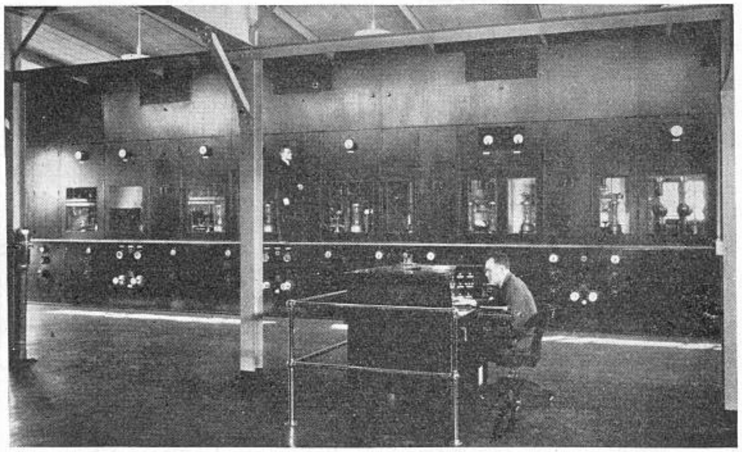

Fig. 2—General view of 500-kilowatt amplifier panel. Amplifiers are to the left, modulators to the right, and main rectifier to the extreme right.

amplifier unit employs four UV-862 tubes in push-pull. There are therefore twelve 100-kilowatt power amplifier tubes and eight 100-kilowatt modulator tubes. All tubes operate at a plate voltage of approximately 11,800 volts.

Conventional layout practice is followed in that all audio and radio equipment proper is located behind interlocked panels on the upper floor, whereas all rotating and power equipment is located in the basement, except for the larger transformers and reactors which are outdoors. The main panel of the transmitter is approximately fifty-five feet long and thirteen feet high. (See Fig. 2.) It is divided into six distinct, individually shielded and individually interlocked units. From left to right, the first three units contain the three power amplifiers, the next two units contain the modulators, and the last unit contains

the main rectifier. The low power audio stages are located behind the modulator units. All of the water controls, including valves, interlocks, and thermometers, and all main tuning controls are located on the front of the main panel. All controls that are used frequently in starting and stopping the equipment are located on the control console.

The main rectifier furnishes voltage for all of the 100-kilowatt tubes and for the 20-kilowatt high power audio tubes. Plate voltage for the lower power audio stages is supplied by a 3000-volt rectifier. For the main rectifier there was developed a new type of tube, the RCA-870. The cathode of this tube requires only 325 watts for heating but produces an actual emission close to 1500 amperes.

To minimize the radiation of radio-frequency harmonics, which are an increasing source of interference from broadcast stations, a low-pass filter is provided between the amplifier output and the transmission line. To reduce further the possibility of harmonic radiation, a concentric transmission line is used. It is supported one foot above the ground and its outer conductor is grounded every twenty feet at the transmitter end of the line. The line termination and antenna tuning circuit is of the simplest type. It forms another stage of low-pass filtering. It has proved itself to be impervious to lightning, having been struck many times.

The operation of the isolation feature of the control circuit is briefly described as follows: If a short circuit occurs in a power amplifier unit (or modulator unit) the plate overload relay associated with the particular tube through which the overload takes place immediately causes the main breaker to open. The total elapsed time from the occurrence of the short circuit to the complete interruption of the 2300-volt primary supply and the extinguishing of the arc is four cycles, whereupon the transmitter immediately goes back on the air. If the short circuit has in the meantime disappeared, operation continues in the normal manner. However if the short circuit persists, the transmitter again shuts down until the defective power amplifier unit has been automatically isolated from the remainder of the circuit, after which the transmitter automatically goes back on the air with a power of about 350 kilowatts. The entire time off the air does not exceed three seconds. A similar sequence of events takes place when a modulator unit isolates, except in this case the equipment goes back on the air after several seconds with full power but with somewhat reduced modulation. It is entirely possible, without any retuning or readjusting of any kind, to operate the equipment with three power amplifiers and two modulators, two power amplifiers and two modulators, two power amplifiers and one modulator, one power amplifier and one modulator, or three power amplifiers and one modulator. When a unit has been isolated it may be entered with complete safety and the filament supply and water supply may be turned off for tube replacement, or other repairs may be made. Each amplifier and each modulator constitutes a complete unit with its own shielding, internal lighting, doors, water interlocks, and forced ventilation.

The major units of this transmitter will be described in more detail in the following sections of this paper.

Substation

Since continuity of operation and general performance of the station depend upon uninterrupted supply of properly regulated power, the power supply system and associated substation were carefully engineered with the coöperation of the Union Gas and Electric Company of Cincinnati. Two 33-kilovolt lines supply power from separate distribution centers and come to the transmitter location over widely separated routes. The substation includes an automatic induction voltage regulator as well as the necessary transformers, lightning arresters and associated equipment required to make available about 1250 kilowatts at 2300 volts and lesser powers at 440, 220, and 110 volts.

Automatically operated oil circuit breakers in each of the 33-kilovolt lines normally connect both lines to the substation input at all times. The control of these breakers is such that any irregularity in either of the power supply lines causes that breaker to open, allowing uninterrupted service from the other line. The opened breaker automatically recloses when power of the proper potential and phase is restored. These breakers may be controlled by push bottons in the transmitter control room when desired.

The use of high level class B modulation introduces a power problem in that there is variation of about 500 kilowatts in the power required by the transmitter occurring at a syllabic frequency. Excessive reactance in the power supply system would result in a type of modulation distortion. It therefore was necessary to use low reactance transformers and regulators and to keep the reactance of the entire system as low as possible. This introduced a protective problem inasmuch as the reactance of the lines and the substation could not be depended upon to limit properly the amount of energy fed into a major fault. To afford suitable protection under these conditions, the main breaker is rated at 50,000 kilovolt-amperes and is designed to open at a higher speed than ever previously used for breakers of this rating.

Physical Layout

The physical layout is one of the most important phases of any transmitter of this type and in this case the size of the apparatus made some of the older constructional ideas look incongruous. The transmitter was made an integral part of the building, and consisted of five separate rooms. This method resulted in a certain constructional gain as the steel uprights within the walls of the rooms were also used to support the roof of the building, thereby using one member to serve

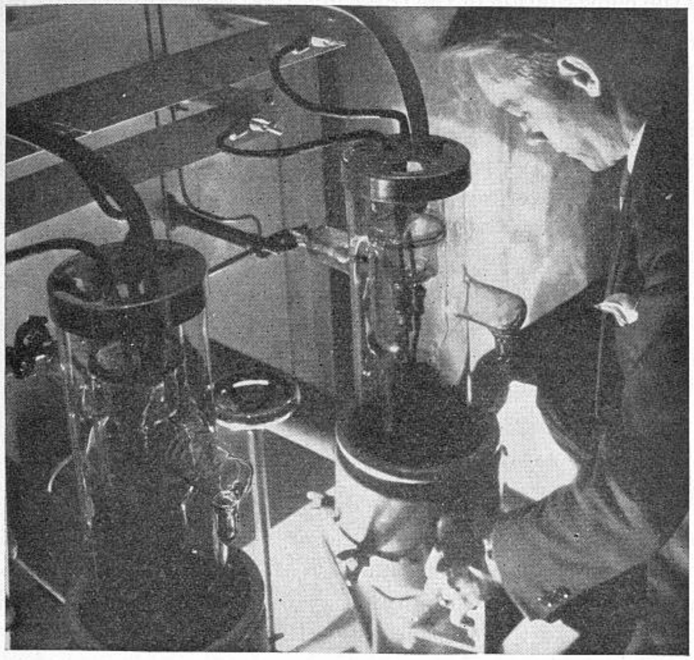

Fig. 3—Clamping a 100-kilowatt tube into its socket.

two functions. Each room or cell is entirely shielded as a unit and these shielded rooms are electrically bonded at numerous points.

The front panels of the transmitter are offset at a horizontal level four feet above the main transmitter floor, thus forming a platform or catwalk running the entire length of the front assembly. Within each cell is an inner catwalk at this same level which furnishes a place to stand to replace tubes, operate filament switches, etc. (See Fig. 3.) The outer catwalk is three feet wide and has covers which are easily removable so that access may be gained to those parts located beneath them. Under the catwalk are housed all of the internal water piping, hose reels, and water temperature and flow instruments. This arrangement of water circuits provides an accessibility heretofore unknown in most broadcast transmitters. The controls are located on the four-foot high panels which run along the front of the transmitter just below the catwalk. All normal adjustments are made from the floor level.

The upper panels form the major frontal surface of the transmitter and are fitted with plate glass windows at eye level. In these upper front panels there are access doors for each cell, opening at catwalk level.

In the construction of the three identical radio-frequency amplifiers several unique features have been evolved. The problem of radio-frequency insulation made it necessary to resort to new styles of insulator design with particular attention given to the prevention of brush discharge. Long-bar green-tint Mycalex was produced by the General Electric Company for this specific application. Specially designed corona shields were added to Mycalex insulators to distribute more evenly the electrostatic gradients. Throughout the amplifier construction particular care was given towards maintaining mechanical symmetry. In addition to this every effort was made to keep the radio-frequency circuits as short as possible. Stray capacities of parts operating at high electrostatic potentials were kept low by grouping, thus tending to reduce the over-all volume to a minimum.

Audio Amplifier and Modulator

The problem presented in the design of the modulation system was unique in several particulars. In the first place the power required of the system was at least ten times greater than that ever before obtained from any audio amplifying system. Furthermore, the fidelity of the system had to be in keeping with the present standards if not somewhat in advance of them. Finally, the output power had to be obtained at an efficiency which was as high as possible. These main requirements governed the design of the modulation system.

After considerable thought had been given to the problem, the following arrangement was decided upon. There are five stages, each stage being connected in "push-pull." The input stage employs two UV-211 tubes. The plate circuit of this stage is coupled by means of a resistance-capacity network to the grid circuit of the second stage, which also uses a pair of UV-211 tubes. The output of the second stage is transformer coupled to the grid circuit of the two UV-849 tubes, which are used as the third stage. In the same manner, the output of the third stage is coupled to the grids of the two UV-848 tubes constituting the fourth stage.

Since the fifth or modulator stage is divided into two units, either one of which must be isolated at times, separate interstage transformers are used to couple the fourth stage to each unit of the fifth stage. These transformers weigh over two tons each. The fifth stage is transformer coupled to the load circuit by means of two identical transformers. These output transformers are rated at 180 kilovolt-amperes each at any frequency from 30 to 10,000 cycles. They are oil-immersed and weigh approximately nineteen tons each. The height over all is approximately eleven feet. The case around each unit is elliptical in shape, having a maximum dimension of seven feet and a minimum dimension of four and three-fourths feet. The direct-current component of the power amplifier plate current is passed through a modulation reactor rather than through the secondary windings of the transformers. The reactor has 4.5 henrys of inductance at 60 amperes. A 50-microfarad, 15,000-volt condenser is connected in series with the transformer secondaries for blocking purposes. The reactor is similar in shape to the modulator output transformers but weighs only twelve tons. The direct-current resistance of this reactor was made especially low to minimize heating losses.

With an input to the power amplifiers of 700 kilowatts, the output power of the modulation system required to give 100 per cent modulation is one half the input power or 350 kilowatts. The power input required for 100 per cent modulation is 12.5 milliwatts. This corresponds to a power amplification of 28,000,000 times.

Current limiting resistors are connected in series with the plates of each of the modulator tubes. These resistors are of such a size as to limit the surge current to approximately 1000 amperes. The power to be dissipated in them is, therefore, 12,000 kilowatts for a time of about one twelfth of a second. To prevent extremely high voltages from appearing across the modulation reactor when the normal plate current for the power amplifiers suddenly decreases in value, a horn gap with a series resistor is connected across the reactor. Had this not been done, it is calculated that voltages in the order of 60 to 80 kilovolts would appear across the reactor if the excitation to the power amplifiers failed suddenly. When a tube flashes internally, approximately the full plate voltage may appear momentarily across the bias supply. To prevent damage to the bias generator, it is by-passed with electrolytic type lightning arresters. These arresters are designed to carry 1000 amperes safely for a short time, and to keep the voltage from building up to more than twice the rating of the machine.

Power for the plate circuit of the first three stages is obtained from a 3000-volt, 2.5-ampere rectifier using six UV-872 type tubes in a conventional circuit.

Power Amplifier

The radio-frequency amplifier, designed and manufactured by the General Electric Company, is composed of three identical unit amplifiers, each delivering approximately 167 kilowatts carrier power. Each amplifier is complete in itself with its own radio-frequency and power circuits. (See Fig. 4.) The four UV-862 tubes in each amplifier are connected in push-pull. The cooling water is fed through special rubber hoses coiled up on a cylindrical form insulated for 50,000 volts

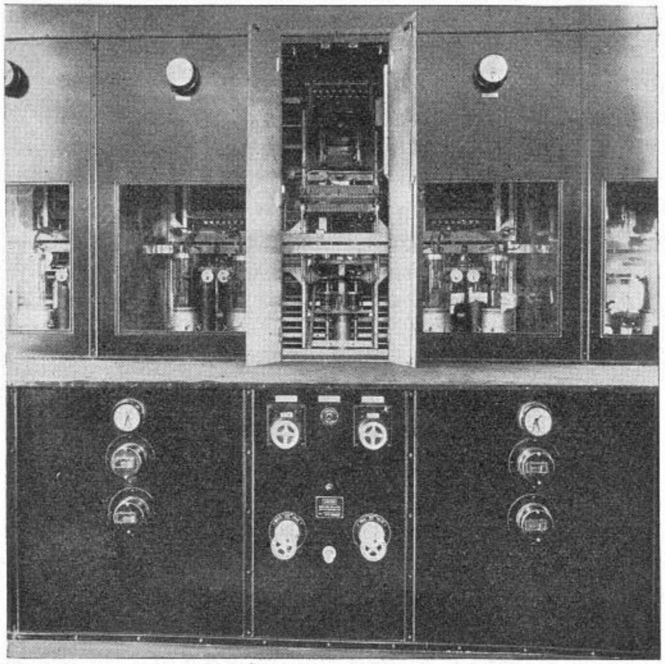

Fig. 4—Front view of power amplifier No. 2, doors opened.

peak potential. The water flowing through each tube is measured by a flow meter having electrical contacts which shut down the transmitter and remove all power from the tubes if the water flow should fall below a specified value. The temperature of the outlet water from each two tubes is checked by a contact-making thermometer which is appropriately connected to the control circuit. Thus the cooling water of each tube in the transmitter is automatically and continuously checked.

Cooling air is supplied to the filament and plate seals of each UV-862 tube. This air supply is checked by an electrical contact-making

device which insures protection to the tubes in the transmitter if the air supply should fail. Approximately 30 cubic feet of air per minute must be supplied to each tube anode and filament seal. A total of 3000 cubic feet per minute is available for cooling the various component

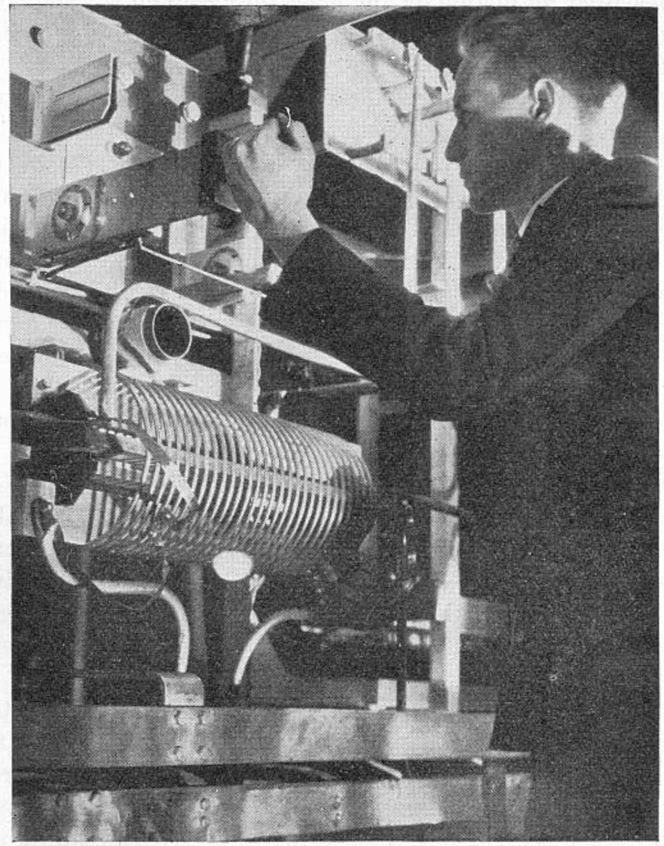

Fig. 5—Detail of filament switch and grid inductance assembly in each power amplifier.

parts of the three amplifiers. Air is drawn out of the top of each amplifier unit by a power-driven fan.

The filaments of the amplifier tubes are lighted from three direct-current generators at a potential of 33 volts. Each tube draws 207 amperes at this voltage. The total filament current for the three amplifiers and both modulators is approximately 4150 amperes. A current limiting resistor is connected in series with the voltage supply circuit to permit gradual heating of the tube filaments in a unit after a tube has been changed.

The bias voltage is derived from a bias generator and self-biasing resistors connected in series with the bias circuit in each unit amplifier. The bias and filament generator voltages are adjusted by rheostats and measured by meters on the operator's control console. The total rectified grid current is measured in each amplifier by a meter on the amplifier panel.

Plate voltage is supplied to each tube through its associated plate choke, which is wound on a glass form. The plate current is measured by a specially developed highly damped meter connected in the plate circuit of each tube. Surge currents in the plate circuits of the amplifier tubes due to internal gas flashes are kept within reasonable limits by individual plate protective resistors having adequate thermal capacity to absorb the stored energy in the rectifier filter and in the modulation reactor, and the energy supplied by the rectifier in the short interval before the rectifier circuit breaker opens. Each amplifier tube has its own plate current overload relay.

The grid excitation circuits for the three amplifiers are connected in parallel and the output coupling coils are in series. After passing through the grid-loading resistor unit, the 500-killowatt amplifier balanced grid line is shielded and split into three lines of equal length which lead to the amplifier grid tank circuits. The individual amplifier grid lines are made equally long to insure grid excitation voltages in phase and to simplify the tuning and loading of the amplifiers. The three grid tank circuits are permanently adjusted to be resonant at the operating frequency. (See Fig. 5.)

Fixed mica-dielectric neutralizing capacitors are used in the conventional balanced neutralizing circuit. This is believed to be the first commercial application of fixed neutralizing capacitors in a broadcast transmitter. The plate tank capacitor of each amplifier consists of two identical air-dielectric capacitors with their center point grounded. This capacitor is unique in broadcast transmitter practice since the plates of the capacitor are made of grids of aluminum tubes. The aluminum tubes are flattened and riveted at their ends to an aluminum angle support. Alternate plates are supported by vertical aluminum pipes. Mycalex insulation is used. The capacitors have been tested for flashover at 50,000 volts, 60 cycles, and normally operate with 7500 volts root-mean-square carrier.

The radio-frequency plate tank inductance consists of copper tubing bent into a spiral or "pancake" coil. (See Fig. 6.) Tuning of the amplifier plate circuit is accomplished by variation of the position of

a half turn of the tank coil about an axis in the plane of this coil, with the control on the front panel. The Q of the tank inductance is over 1200. The secondary or coupling coil consists of a similar spiral-wound coil coupled to the tank coil, with its position with respect to the tank coil adjustable by a control on the front panel. An electrostatic shield

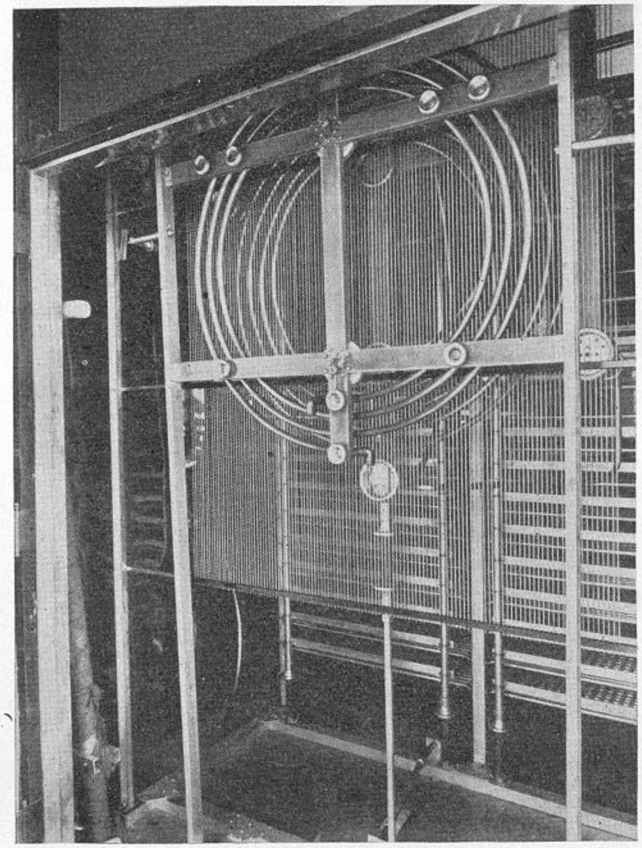

Fig. 6—Rear view of a power amplifier showing tank and coupling coils, electrostatic shield, and air dielectric tank condensers.

consisting of a number of parallel conductors in a plane, joined together and grounded at one end, is interposed between the tank and coupling coils to reduce the electrostatic coupling between these two coils.

The harmonic filter unit is located in the basement below ground level. It consists of a single T section low-pass filter with the three amplifier coupling coils forming the first inductive section. The input circuit of the harmonic filter may be switched either to the 50-kilowatt output circuit or to the 500-kilowatt set. (See Fig. 7.)

The concentric transmission line which transmits the power to the antenna house is 780 feet long and is constructed close to the ground to reduce its effective height for harmonic radiation. (See Fig. 8.) It is well grounded at short intervals near the transmitter end. The surge impedance of the line is 100 ohms, thereby making the line voltage 7070 volts and the line current 70.7 amperes for unmodulated 500 kilowatts. A surge impedance of 100 ohms was decided upon after a study of flashover potentials in this type of concentric line and after antenna resistance measurements were made. The ratio of outside to inside diameters for optimum flashover potential in a practical line is greater than the theoretical ratio $e=2.718$ due to the necessity of using corona shields in conjunction with the inner conductor insulators. The

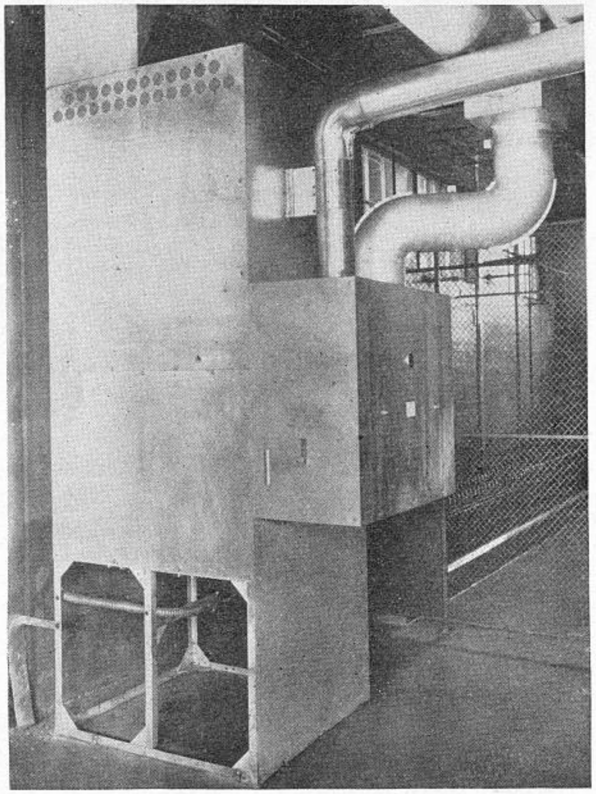

Fig. 7—Harmonic filter.

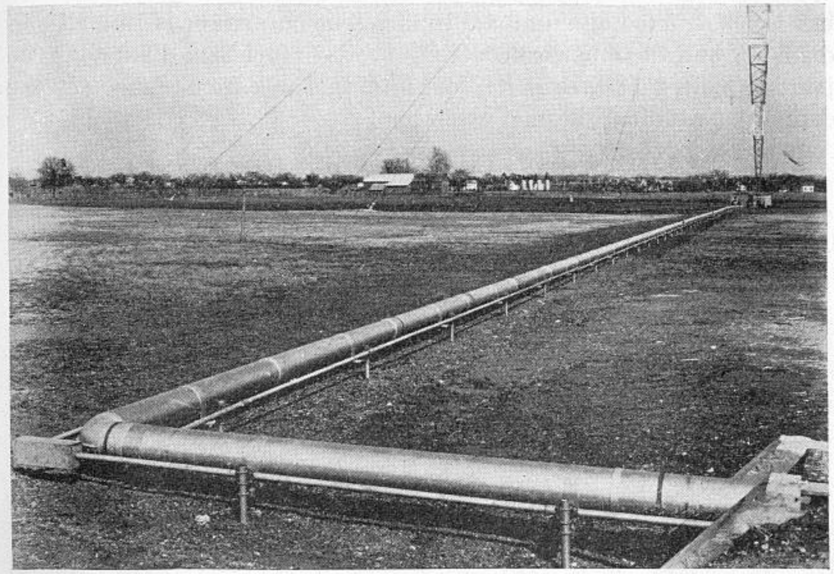

Fig. 8—Seven hundred and eighty foot concentric tube transmission line.

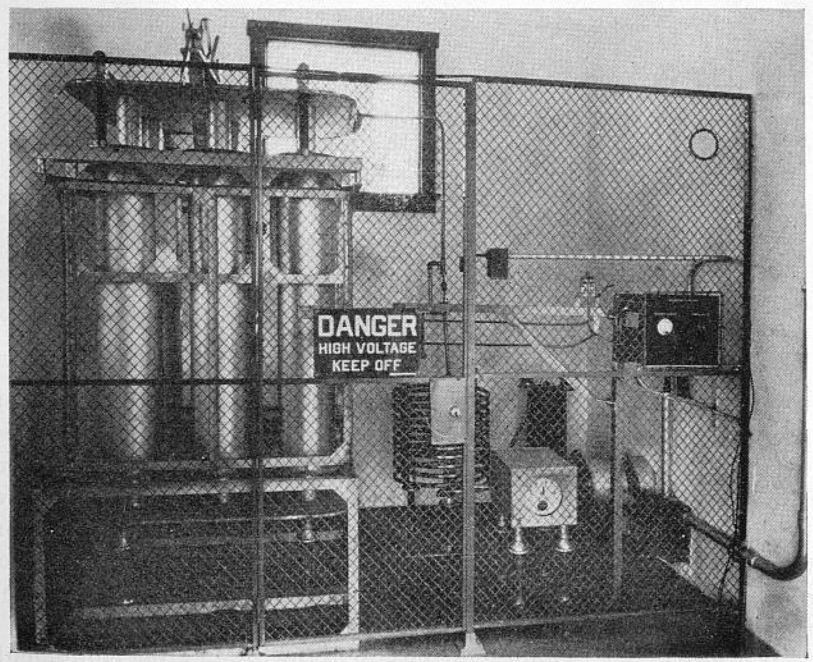

Fig. 9—Antenna tuning house equipment.

line is constructed of aluminum tubing. The outer tube is 10 inches in diameter and the inner concentric tube 1.875 inches in diameter. The joints of both tubes are at ten-foot intervals and are designed to take care of longitudinal thermal expansion.

Antenna Coupling Equipment

The antenna house equipment is shown in Fig. 9. The transmission line is terminated in a simple impedance matching circuit consisting of an inductance coil between line and antenna, with a capacitor to ground from the antenna. The antenna-ground capacitor consists of six concentric tube units with the outer tubing of each unit 10 inches in diameter and the inside tube about one third as large. The voltage on the base of the antenna for 500-kilowatt output is approximately 14,000 volts root-mean-square with zero modulation. The capacitor was tested for flashover at 80,000 volts at 60 cycles. It is variable, and in conjunction with the antenna impedance and the series inductance, it permits the line to be terminated in a resistance of 100 ohms.

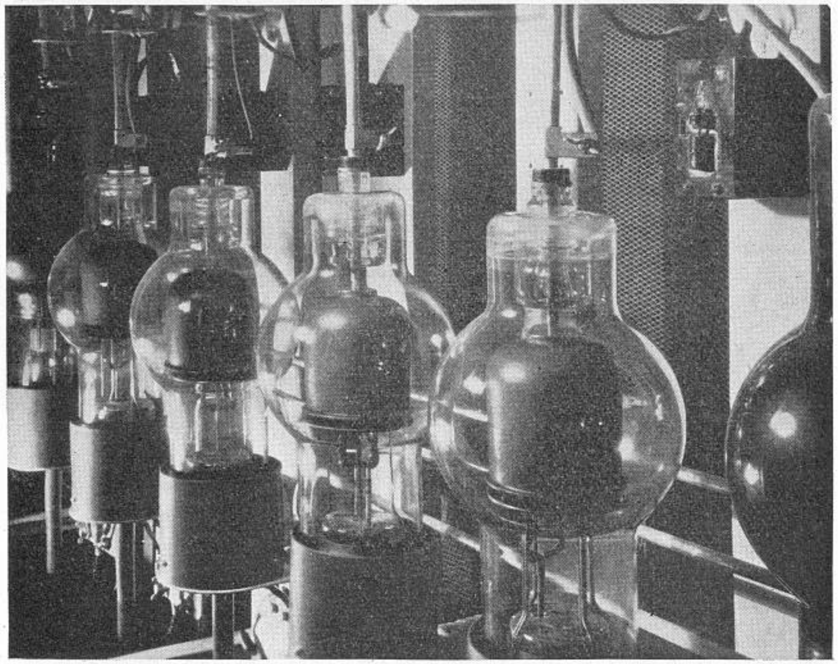

Fig. 10—RCA-870 tubes in 1250-kilowatt main rectifier.

It is interesting to note that the size of the terminating equipment is only about one half that usually used in a 50-kilowatt transmitter.

It is believed that the concentric transmission line is being used for the first time in a high power broadcast transmitter in the United States, and that this line is the longest and largest in the world.

Main Rectifier

Plate power for all water-cooled tubes in the equipment is supplied by the main rectifier. Sufficient rectifier capacity has been provided in the main rectifier to supply plate power to the output stage of the 50-kilowatt exciter if desired.

Six RCA-870 hot-cathode, mercury-vapor rectifier tubes are used in the main rectifier (see Fig. 10), each approximately 24 and one-half inches long. The maximum peak inverse voltage rating of these tubes is 16,000 volts and the maximum instantaneous anode current is 450 amperes. The average anode current rating is 75 amperes, provided that the operating frequency is 25 cycles or more. These tubes are operating considerably under their maximum rating in this application.

The rectifier circuit employed is essentially the three-phase, full wave arrangement described previously by Steiner and Maser.[1] Three single phase plate transformers are used, weighing about 7000 pounds each. The primaries may be switched to either Y or delta connection by means of two solenoid operated oil circuit breakers. This scheme permits warming up or testing the equipment with the plate voltage lowered to approximately 7000 volts. Each plate transformer is provided with a manually operated primary tap changing switch to obtain output voltages five and ten per cent above and below the two normal values. The rectifier circuit differs slightly from the conventional three-phase, full wave connection in that the plate transformer secondaries are connected in delta. This arrangement provides one set of delta windings between the rectifier and the supply line for low voltage testing and two delta connections for full voltage operation of the rectifier, thus reducing third harmonics of supply frequency and odd multiples thereof in the power lines supplying the station.

The rectifier could be given a continuous output rating of 1250 kilowatts, but the nature of the load under conditions of varying percentage modulation makes this type of rating of little value as a criterion of performance. The direct-current load current varies from about 70 amperes at zero modulation up to approximately 110 amperes for 100 per cent sustained modulation, due to the class B operation of the high level modulator stage.

For this type of load, it is of prime importance that the rectifier

[1] H. C. Steiner and H. T. Maser, "Hot-cathode mercury-vapor rectifier tubes," Proc. I.R.E., vol. 18, p. 80; January, (1930).

voltage varies a minimum amount. Factory tests on the three plate transformers indicate that the average alternating voltage drop for this load variation was 0.88 per cent of normal voltage, at 90 per cent power factor. The resistance of all circuit elements between the rectifier tubes and the modulator load is kept at a minimum. The reactance of all circuit elements on the alternating-current side of the rectifier is kept at a low value.

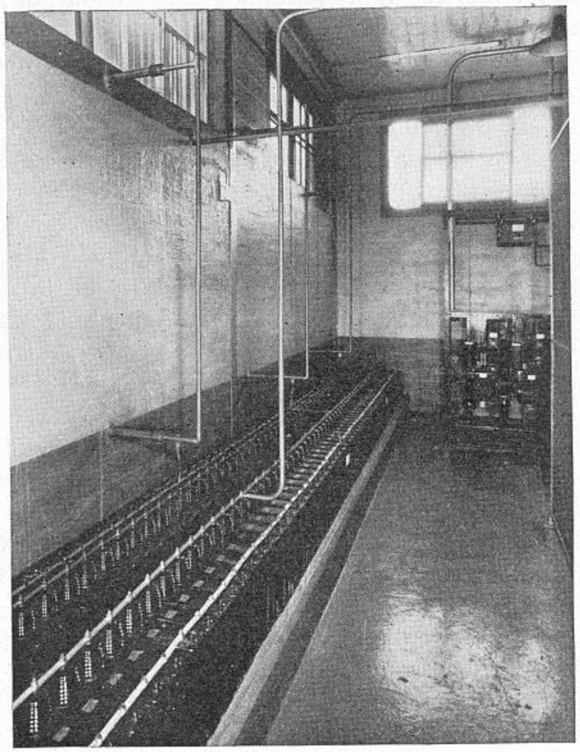

Fig. 11—Main filter condenser.

Since there is so little regulation producing impedance in the rectifier power supply and the rectifier itself, it was mandatory that high speed circuit protection be provided in case of rectifier tube arc-back or overload on the rectifier output. This was provided in the form of a specially developed high speed, solenoid operated oil circuit breaker. Factory tests showed that this circuit breaker required an average of 2.2 cycles (on a 60-cycle basis) from the energization of the trip coil to the parting of the contacts. The over-all time from the beginning of the overload to the actual interruption of the current in the 2300-volt

supply is about double this value, since relay time and arcing time at the power contacts must be included.

The rectifier proper is not required to supply power at an audio-frequency rate because the filter capacitor has adequate stored energy for this purpose. The filter capacitor bank is rated 171 microfarads, 15,000 volts direct current and is composed of 114 paralleled, 1.5-microfarad capacitor units of the Pyranol type. (See Fig. 11.) Direct current is blocked off the secondaries of the modulation transformers by a bank of 33 identical capacitor units. Considerable progress has been made in the reduction of space requirements for this type of capacitor since the dimensions of a single unit are $4\frac{1}{4}$ by $13\frac{1}{2}$ by $17\frac{1}{4}$ inches high over the terminal. A one-fourth henry reactor completes the rectifier output filter. The ripple in the direct load current is extremely low and the radio-frequency carrier ripple from all sources is approximately 66 decibels down from 100 per cent modulation. The resonant frequency of the filter system, including the modulation reactor and other elements in the power amplifier plate supply circuit, is about 26 cycles, which is well below the usable audio range. A high-pass filter is incorporated in the audio input system to prevent the possibility of frequencies as low as this from being supplied to the modulator. The possibility of audio distortion due to inadequate filter capacity has been previously suggested by Kaar.[2]

A starting resistor is used in series with each of the three 2300-volt, 3-phase, 60-cycle lines to the plate transformer primaries. These resistors are used to absorb the switching transient, and are automatically short-circuited by means of a solenoid operated oil circuit breaker after they have been in the circuit about one second.

The RCA-870 rectifier tube utilizes an indirectly heated type of cathode. The heater, which requires 65 amperes at 5 volts, must be energized 30 minutes before the application of plate voltage to insure adequate cathode emission and correct operating temperature of the mercury vapor. Provision was made in the control circuit of the rectifier to turn on the cathode heaters at a predetermined time each morning by the use of an automatic time switch. Provision is made to remove heater voltage at the end of the thirty-minute heating period if the rest of the equipment is not started up. It is also possible to preset the switch so as to omit automatic application of voltage any desired days each week. In normal starting, a direct-current motor-operated time delay relay prevents the application of plate voltage until the cathodes have heated thirty minutes.

[2] I. J. Kaar, "Adjacent channel interference," Proc. I.R.E., vol. 22, p. 312: March, (1934).

Rectifier filament voltage is applied in two steps to prevent high initial inrush current. Since the entire transmitter is supplied from a voltage regulated source of power, the danger of operating the rectifier filaments at other than rated voltage is not great. However, since operation much below rated voltage is destructive to the tubes, a filament undervoltage warning and protective scheme is incorporated in the design. An induction type undervoltage relay was used since an inverse time characteristic is inherent in its operation; it is not desirable that a warning should be given on line voltage changes of a transient nature. If the primary voltage on the filament transformers drops more than five per cent below normal, a warning bell rings. If the operator has not readjusted the filament voltage after a few seconds, plate voltage is automatically removed. During operation, a spare rectifier tube is warmed up ready to be used in replacing any active tube which might fail.

Preheated air is supplied to the chamber around the base of each rectifier tube. The temperature of this air is thermostatically controlled to insure that the tube will always operate at a nearly constant temperature for which it is designed. A rectifier air temperature indicator is mounted on the front of the rectifier panel. Meters are provided on the front of the panel for rectifier output voltage, total rectifier load current, filament transformer primary voltage, and filament hours.

In common with the doors of all other transmitter units where dangerous voltages are present within, the rectifier access doors are interlocked to remove plate voltage when a door is opened. A safety bar must be raised before an operator can walk into the rectifier compartment. The raising of this bar mechanically operates a switch which disconnects the alternating-current line from the plate transformer secondaries and grounds the direct plate voltage circuit.

This equipment provides the first commercial application of RCA-870 rectifier tubes. It is believed that this rectifying equipment, which can be conventionally rated at 1250 kilowatts, has a higher output current rating than any rectifier previously built for operation at plate voltages as high as 12,000.

Cooling System and Rotating Equipment

The cooling system provided to take care of the heat incident to the operation of the equipment may well be divided into two groups; namely, the water-cooling system and the air-cooling system. Each 100-kilowatt tube in the equipment requires about twenty gallons of water per minute. In addition, the cooling system is designed to be adequate for the existing 50-kilowatt exciter. Thus the total amount of water required to be delivered by the pure water pump is about 525 gallons per minute. The pump is driven by a 20-horse-power motor and is made of bronze and brass. No ferrous materials are used anywhere in the pure water system. The pure water is circulated through two heat exchangers. These exchangers consist of a number of brass tubes fitted into headers at each end. The bundle of tubes thus formed is placed in a large pipe. The pure water is circulated through the brass tubes while the pond water is circulated through the pipe which encloses them. Each heat exchanger has 235 square feet of area across which heat is transferred from the pure water to the pond water. The two exchangers together will take care of 850 kilowatts of heat continuously with a temperature difference of about ten degrees Farenheit between the pure water and the pond water.

The pond water is discharged through spray nozzles into a pond seventy-five feet square holding about 120,000 gallons of water. Sixteen spray nozzles are available for use under the most adverse conditions. Provision has been made so that the amount of water flowing to the nozzles can be controlled from a maximum of 800 gallons per minute to any smaller amount desired. For operation in the winter the water is discharged directly into the pond without going through the spray nozzles.

The air-cooling system consists of a single motor-driven blower connected to a duct through which the air is forced. The main duct has branch ducts leading to each plate seal and each filament seal of the twenty UV-862 tubes used in this equipment. Each branch duct is fitted with butterfly valves by means of which the flow of air can be equalized between tubes. The blower is of the centrifugal type and is designed to blow 3000 cubic feet of air per minute against a static pressure of four inches of water. To permit the total amount of air delivered by the blower to be controlled to suit the conditions, the motor used is a direct-current, variable speed motor, rated at approximately three horse power. The speed is varied by means of a rheostat. The rotating equipment, aside from the water pumps and air blower, consists of the shop machine, the filament motor-generators, and the bias motor-generators.

There are three filament motor-generator units. Each motor, rated at 85 horse power at 1175 revolutions per minute operates from the 2300-volt, 3-phase, power supply. The motor is of the "line start" type which requires no voltage reducing device for starting and hence simplifies the starter problem. The generator driven by the motor is rated at 35 volts direct current, 1500 amperes. It is designed for minimum ripple. The ripple amplitude is less than one per cent of the amplitude of the terminal voltage. The commutator has radiating fins which also act as a blower, keeping air blowing over the commutator bars. Three of these machines were chosen in place of one large machine so that if it becomes necessary to service any unit it will not be necessary to shut down the entire equipment. Each unit has an individual control panel by means of which the machines can be started or stopped independently if desired. An ammeter is supplied for each unit to facilitate load adjusting.

The bias motor-generators are supplied in duplicate, one machine being active and the other held in reserve as a spare. Each unit consists

Fig. 12—Operator's control console.

of three generators driven by a common motor. Two of the generators are mounted in one frame. The motor is rated at 17.5 horse power at 1750 revolutions per minute. Of the three direct-current generators, the generator which supplies bias for the power amplifier tubes is rated at 12 kilowatts and delivers 1000 volts. The bias generator for the modulators is rated at 1.2 kilowatts at 100 volts. The generator furnishing bias for the first four audio stages is rated at 0.375 kilowatt at 1500 volts. These machines are designed to have a very low value of ripple voltage. The ripple voltage is less than one per cent of the terminal voltage. One interesting feature of the design is that the bias generator for the power amplifiers and to some extent the bias generator for the modulators really act as motors when the equipment operates normally. Thus the motor normally driving the generators must be capable of acting as a generator supplying power to the 220-volt line.

Control Circuit

The control switches, indicator lights, relays and other devices associated with the automatic sequence and protective control cir-

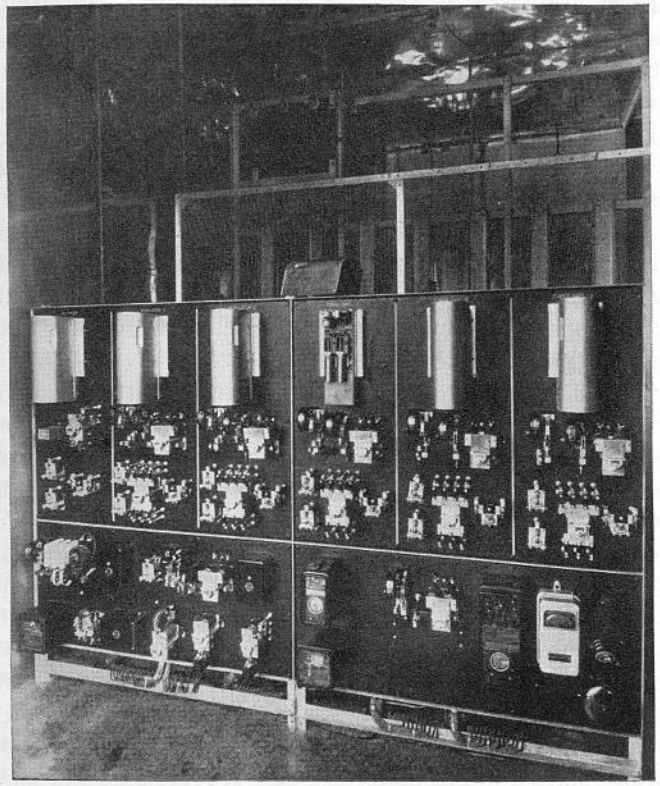

Fig. 13—Control relay panel.

cuits are centralized, rather than being located at various more or less inaccessible places about the transmitter. All of the sequence control switches and voltage changing controls with the associated meters and indicator lights are grouped on the operator's console. (See Fig. 12.) These devices are those normally used by the operator in starting or shutting down the equipment and in making adjustments during operation. The relays and contactors associated with these circuits are located on a control panel behind the main rectifier unit, Fig. 13.

All parts of the control panel and console are noninterlocked. They are completely accessible during transmitter operation. No dangerous voltages are present on either the control panel or the console. Relays having coils or contacts in high voltage or high current circuits are of necessity located at those places in the equipment where the high voltages and currents occur.

The sequence switches located on the console can be preset for automatic start-up of the equipment from a single push button (with the exception of two manual steps) and the equipment can be automatically shut down from another push button. All voltages and cooling agents are applied and removed in the proper sequence. Since the operator will generally wish to check instrument readings as the equipment is being started, sequence switches are provided on the console to permit starting the transmitter automatically, up to any preset status, where it will remain until another manual switch is operated to change the status. These sequence switches may also be utilized in shutting the transmitter down, step by step. The control circuits are so wired that operation of the sequence switches in improper order will result in no damage to the equipment.

No appreciable time delay occurs at shutdown except that the complete water- and air-cooling system operates for ten minutes after voltages are removed from the vacuum tubes, since the elements of the water-cooled tubes have considerable thermal capacity. Complete shutdown is effected by operating the "transmitter-off" switch. Each of the sequence switches is provided with a red indicator lamp which lights when the corresponding status has been reached in manual or automatic starting.

The direct filament voltage and the bias voltages for the radio-frequency power amplifiers, audio amplifier, and modulators may be separately varied and the voltages checked by rheostats and meters located on the console. An antenna ammeter, 2300-volt line voltmeter, and overmodulation alarm meter are also provided.

Transmitter and plate voltage controls and indicator lights for the 5-kilowatt broadcast transmitter WSAI and the high-frequency transmitter W8XAL are also located on the console. Among the items of general utility to be found on the console are an electric clock, status indicator lights for the two 33-kilovolt, alternating-current power lines, telephone and telegraph drop signals and jacks, two 115-volt alternating-current outlets, a folding typewriter stand, volume indicator jacks, and a radio-frequency "carrier-on" neon lamp.

Each water-cooled tube is provided with a direct-current overcurrent relay. Each of these relays is provided with an auxiliary set of

contacts connected to annunciator type drop signals. These drop signals are all located near the operator's position at the console so that he may immediately know the location of the relay which has operated.

The controls for a Thyratron type overmodulation alarm system are located on the console. An alarm, given when a given percentage modulation has been exceeded, consists of a buzzing noise and a flashing neon lamp. The percentage modulation above which the alarm is to be given can be adjusted by a voltmeter calibrated in negative modulation percentages between 50 and 96 per cent. The device is operated on the modulated direct-current output from a radio-frequency rectifier located in the antenna house.

Manual filament disconnect switches are provided in each power amplifier and modulator unit to permit removal or application of filament voltage in two steps. These filament switches are provided with interlocks which short-circuit the flow interlock contacts of an isolated unit when the switches are completely open. This permits the flow of cooling water to be shut off safely in the faulty unit without influencing the operation of the rest of the transmitter. Servicing operations, including tube changes, may thus be made in safety during the operation of the rest of the equipment. The carrier off time required to place manually or automatically a unit in service or remove it does not exceed three seconds.

A transmitter unit may be manually isolated by means of the appropriate unit "off" switch on the operator's console. It may be automatically isolated in two ways. The unit is automatically removed from service if a momentary opening of the series plate control circuit for that unit occurs twice within one minute, or if a sustained opening of this control circuit occurs for five seconds or longer. The momentary openings would generally be occasioned by the operation of a direct-current overcurrent relay in the unit, although they might be caused by transient operation of the water overtemperature interlocks or of access door interlocks. The sustained opening would generally be caused by water overtemperature or by the opening of an access door.

Vertical Radiator

The investment that is justified in the radiating system of a broadcast station depends chiefly on the investment in the transmitter, on the frequency being used, on the local ground characteristics, and on the type of service desired. For each broadcast station, a separate study is required to find the most economical type of radiator. A study of the conditions existing at WLW indicated that, when using a power of 500 kilowatts, a very large investment in the radiator would be justified. Plans were therefore made to install a vertical radiator of 0.58 wavelength height since this was the best practical type of radiator known at the time.

The entire radiator, including insulators, was designed for 500-

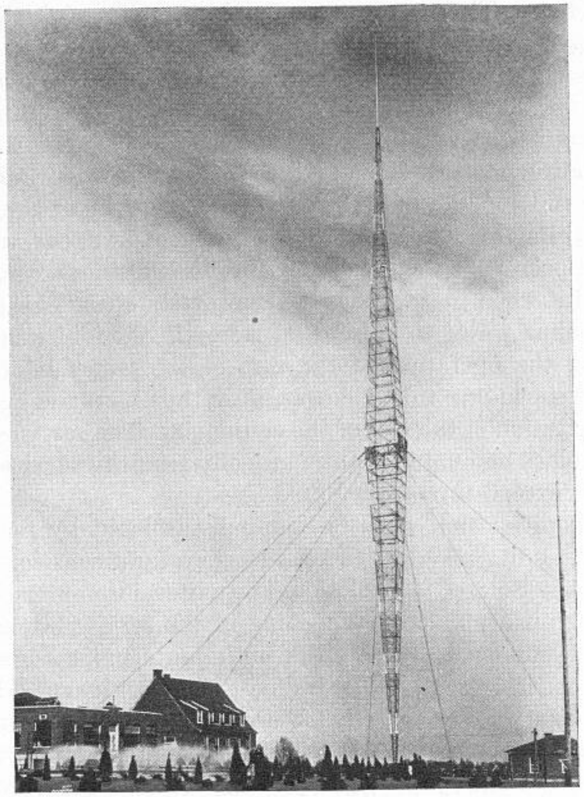

Fig. 14—The WLW 831-foot vertical radiator. 120,000-gallon spray pond in the foreground.

kilowatt operation. The height is 831 feet. (See Fig. 14.) The widest section, thirty-five feet across, is at the 350-foot level. The tower rests on a single porcelain base insulator and is held in position by eight two-inch guy cables. Each cable is broken up with seven insulators. The total load, including 136 tons for the tower proper and including additional loads due to the down-pull of the guy wires and to certain weather conditions, reaches peaks of 900,000 pounds. The base in-

sulator rests on a concrete foundation which spreads out under ground and is supported by twenty-four piles driven to a depth of approximately seventy feet.

Sufficient lighting for warning of airplanes is essential since the tower is only a short distance from an established air route. The lighting consists of two one-kilowatt red Fresnel beacons mounted at the top of the steel structure, and a number of 100-watt red obstruction lights at different elevations on the tower. A "WLW" sign, thirty-five feet across and ten feet high, is installed at the 350-foot level. This sign is constructed of double neon tubing and is visible for many miles

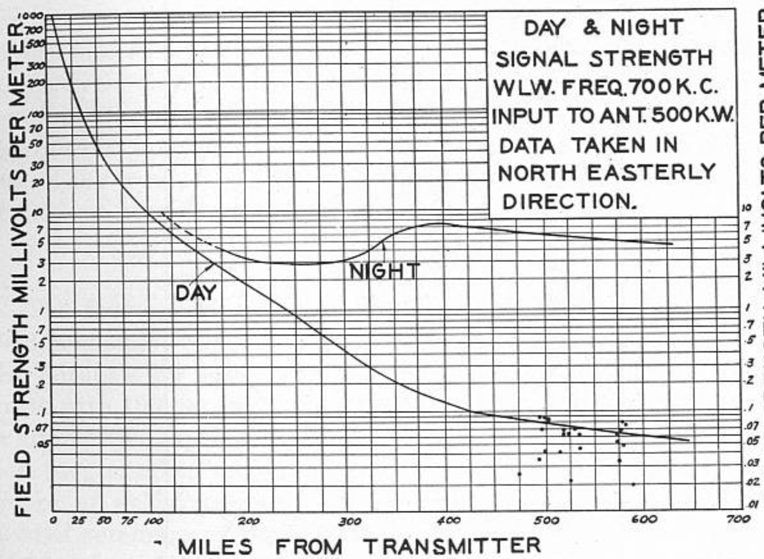

Fig. 15

at night. Both it and the Fresnel beacons are flashed on and off by a flasher mounted in the tower. In addition, there is a 24-inch red revolving beacon mounted near the base of the tower to indicate to all airmen a hazardous area. The 220-volt, 60-cycle power required to operate the tower lights is supplied through a filter system installed in the antenna house. This double conductor filter adequately passes the 60-cycle supply but presents a high impedance at 700 kilocycles. The high voltage end of the filter, instead of being connected directly to the antenna, is connected to the line end (low voltage end) of the antenna inductance. Thence the 60-cycle leads are threaded through the tubing of which the antenna inductance is wound.

The vertical radiator was put into service in June, 1933, and a quantity of data was obtained on the comparison of this antenna with the conventional T antenna that had been in use at WLW for many years. The T antenna was of the conventional type, supported by two 300-foot towers. It operated at approximately 0.75 of its fundamental wavelength. By leaving the T antenna installed and by arranging to switch the 50-kilowat transmitter from it to the vertical antenna, there

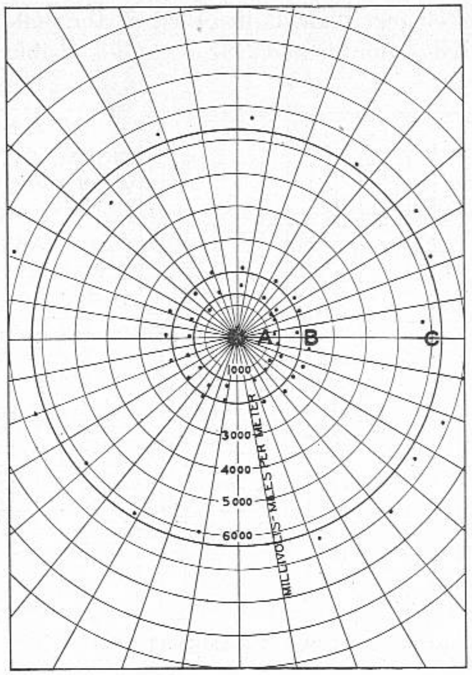

Fig. 16—Relative field intensities, quarter-wave antenna and vertical power.
Curve A: Field intensity, 50-kilowatt input to quarter-wave antenna.
Curve B: Field intensity, 50-kilowatt input to 0.58-wave antenna.
Curve C: Field intensity, 500-kilowatt input to 0.58-wave antenna.

was afforded the opportunity of getting absolute comparisons between them at all times of the day and under various conditions. Absolute field strength measurements were taken with calibrated instruments and several recording instruments were used to record fading. So far as is known, this is the first case where absolute comparisons could be made between the two types of antennas, with all other conditions, including power, frequency, location, and radiation, remaining the same. The measured results agree with the calculated prediction within the limits of measurements. (See Fig. 15.)

Fig. 16 shows field strength contours for the two antennas. Assuming that receivers without automatic volume control produce satisfactory signals when the fading does not exceed six decibels, and assuming that receivers with automatic volume control produce satisfactory signals when the fading does not exceed twenty decibels, it is found that the area of nonfading service for the first type receiver was increased 66 per cent by the vertical radiator, and the nonfading area for the second type of receiver was increased 186 per cent. Both of these increases are due to the antenna alone as they are derived from measurements based on 50-kilowatt power. The average increase of field intensity in the secondary coverage area, based on hundreds of measurements, was 39 per cent. Thus the vertical radiator produces an increase of field strength equivalent to doubling the transmitter power, in the case of WLW. This would not necessarily be true at other locations since the efficiency of the vertical type radiator, both with regard to its intensification of the ground wave as well as to its reduction of sky wave, depends considerably upon the electrical properties of the immediately adjacent earth.

Performance

The first equipment arrived on the field approximately July 1, 1933, and on November 1st of that year 500 kilowatts were put on the air. Within a few days this power was increased to well over 500 kilowatts with 100 per cent modulation. No change of major importance or appreciable expense was found necessary in the design. The installation progressed in accordance with a schedule formed many months before, an achievement all too rare in broadcast installation history. A brief summary of the tests is given below to indicate the general performance of the equipment under typical operating conditions.

The normal power output is 525 kilowatts. The normal power input to the 500-kilowatt amplifier including all auxiliary apparatus, but excluding the 50-kilowatt exciter, is 1150 kilowatts for zero modulation, 1600 kilowatts for 100 per cent sinusoidal modulation, and 1225 kilowatts for normal average modulation. The level of the residual carrier hum is 66 decibels below the level corresponding to 100 per cent modulation.

The over-all audio harmonics present in the modulation envelope increase from zero at zero per cent modulation to 5.3 per cent root-mean-square at 95 per cent modulation. The variation of audio harmonics with the per cent modulation is shown in Fig. 17. The reference frequency was 200 cycles. At lower frequencies the harmonic content is practically unchanged; at higher frequencies it is lower than indicated in Fig. 17. In making these measurements, tubes that were somewhat unbalanced were purposely used so that the results would represent typical operating conditions rather than optimum conditions obtainable with tubes selected for balance.

The frequency characteristic, measured at 50 per cent modulation, is one decibel below the 1000-cycle value at 30 cycles, one decibel low at 50 cycles, one-half decibel low at 150 cycles, thence zero decibel to 5000 cycles, one-half decibel low at 8000 cycles, and two decibels low at 10,000 cycles. One hundred per cent modulation is obtainable at all frequencies between 30 and 10,000 cycles.

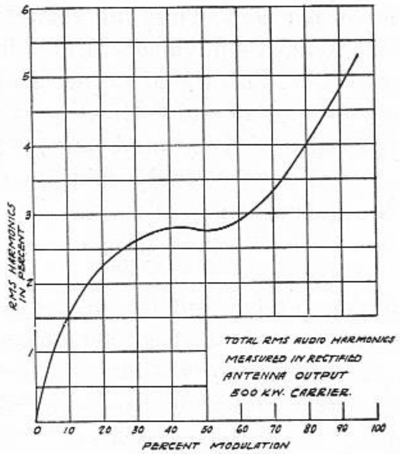

Fig. 17

With a fundamental field strength of six volts per meter at one mile, the strength of the strongest radio-frequency harmonic (the second) is 400 microvolts per meter at one mile. This means that this harmonic, so far as radiation along the ground is concerned, has a strength of 0.002 watt as compared to 525,000 watts for the fundamental. The fourth radio-frequency harmonic does not exceed 200 microvolts and the third, fifth, and sixth are below 50 microvolts.

It is believed that these performance characteristics are somewhat in advance of the present requirements of the broadcast art, and that in general they represent the greatest degree of excellence which is at present economically justifiable.

Proceedings of the Institute of Radio Engineers
Volume 22, Number 10 October, 1934

THE MEASUREMENT OF HARMONIC POWER OUTPUT OF A RADIO TRANSMITTER*

By

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Summary—*A method of determining the harmonic power output of a high-frequency radio transmitter is described. It is a method for measuring the power delivered by the transmitter to the antenna system, as distinguished from the more common method of measuring harmonic field strengths at specified locations. It is essentially a comparison method. The unknown harmonic power, present with the fundamental, is compared by means of a sufficiently selective receiving set with a known comparison power which is supplied in the absence of the fundamental. The method in practice seems to be accurate within about one decibel. It is applicable to the measurement of power other than harmonic power.*

Efforts to obtain reasonable power outputs and efficiencies from radio transmitters have, in general, resulted in the use of the vacuum tubes in the last stage as nonlinear amplifiers. One of the results has been the generation of various undesired components, including harmonics of the carrier frequency. The harmonics are, in general, modulated in about the same manner as is the fundamental. Such radiations may cause interference with other services and their control therefore becomes important.

To formulate logical limits, and to know whether a transmitter is being held within proposed limits, there is required a method of measuring the amplitude of the spurious radiation and correlating that with the interfering effects. Considerable work has been done at frequencies below 1500 kilocycles toward establishing a correlation between the interfering effect at distant points and the field intensity of the harmonic at a fixed distance from the radiating system.

If we confine our attention to the short-wave range, however, we find it increasingly difficult to arrive at any such correlation. The nature of propagation of short waves is such that the interfering signal may appear at points hundreds of miles from the transmitter while not appearing at closer points. Since the physical dimensions of the antenna system are probably of the order of several wavelengths at the harmonic frequency, erratic directive radiation characteristics may result and interference may occur only in a few unpredictable directions. These considerations make measurements of harmonic field strengths

* Decimal classification: R251. Original manuscript received by the Institute, May 29, 1934. Presented before Ninth Annual Convention, Philadelphia, Pa., May 29, 1934.