CBS International Broadcast Facilities*

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Summary—*This paper describes the present significance of international broadcasting; its growth and present status in both the Eastern and Western hemispheres; factors governing service to Columbia's new Latin American international network consisting of sixty-four stations located in eighteen different countries; the many problems attendant upon successful relaying of programs to these many points; facilities for this service, including new studios, frequency-modulation program-relay circuits, and two complete 50-kilowatt transmitting plants located at Brentwood, Long Island, New York; features of design and operating performance characteristics of the transmitting apparatus, including thirteen directive antenna arrays and their associated transmission lines. A typical international radio relay receiving-station installation and the importance of properly engineering such facilities, will also be briefly discussed.*

Introduction

RADIO broadcasting means the dissemination of radio communications intended to be received by the public, directly or by the intermediary of relay stations. In the broadest sense, this applies both to short-wave and medium-wave broadcasting. The chief difference between the two lies in the public involved. Whereas medium-wave broadcasting is intended to be received by a public located in the country originating the broadcast, short-wave broadcasts are designed for the public of one or more other countries than that of origin.

The Columbia Broadcasting System is, at the present time, constructing two new 50-kilowatt international broadcast stations and thirteen directive antenna arrays near Brentwood, Long Island, a sparsely populated location, approximately 37 miles east of the New York studios.

Before discussing the purpose and technical aspects of this modern short-wave transmitting plant, it would be well to review briefly the history and present-day significance of international broadcasting.

History and Significance

Broadcasting by short-wave began experimentally during 1924. In the United States, this service was then known as "experimental relay broadcasting." Considerable activity took place in other countries at about the same time, notably in Holland, England, and Germany. The development of this service moved along slowly until the early 30's, when it became more active in both England and Germany. At about this time, the Empire Broadcasting Service of the British

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Broadcasting Corporation was inaugurated.[1] It was not, however, until about 1935 that the importance of international broadcasting became fully recognized by the various countries using it and the race for frequencies and high-power facilities began. During 1936 and 1937, the number of stations tripled, the total number being more than three hundred. Today there are more than one hundred stations of this class in South America alone. In 1937, England, Germany, Italy, the United States, and a little later, other countries including Japan, began transmitting a large number of foreign-language programs utilizing Spanish, Portuguese, French, German, and English languages for the most part. Many of the European transmissions were directed toward the Americas, particularly Latin American countries. It is not the purpose of this paper to discuss propaganda broadcasts or any other subject in this catagory, but as a result of recent history, the significance of international broadcasting has been well established.

During 1940, executives of the Columbia Broadcasting System visited eighteen Latin American countries and made arrangements for sixty-four or more broadcast stations in these countries to become associated with a new CBS international network. It is significant to note that this message was carried to, and left with, the various countries visited.

> The solidarity and, to a great extent, the security of the Western hemisphere will depend upon the amount of sympathetic understanding prevailing among the peoples of all the American nations.
> That is why we are now building new radio facilities; facilities which will be devoted entirely to the development of a closer friendship among the twenty-one neighbor republics of America; disseminating information, music, education, and entertainment through the magic of short-wave radio.

This journey was undertaken to determine, on the spot, what could be done to further good-neighbor policy with South and Central America and the West Indies. The investigation demonstrated conclusively that transmitting North American programs to Latin America by short waves was not enough since most persons in those countries listen to their local station broadcasts just as they do in the United States.

For this reason, CBS has contracted with medium-wave outlets in twenty countries to carry regular day-by-day broadcasts of specially built programs. The new network already consists of thirty-nine medium-wave and twenty-five short-wave stations, the latter to serve interior points.

While the primary purpose of the new far-flung network is to promote better relations with Latin America, the commercial radio possibilities of these countries will also be developed, thus promoting an exchange of goods as well as an exchange of ideas.[2,3] In the United States, international broadcasting is a commercial radio service and, in this respect, is unlike similar service from other countries which is, in most cases, government controlled.

CBS International Broadcasting

CBS has been transmitting short-wave programs since 1930. During the first few years this operation consisted of experiments of a technical nature. Network programs were transmitted on irregular schedules, using composite, comparatively low-powered single-frequency equipment and a nondirectional antenna. In 1932, W2XE, the former call letters of WCBX, known to many radio experimenters and amateurs, installed a new 1000-watt station, and in 1937, a 10,000-watt station, which, combined with a few directional antennas, greatly improved service.

Technical developments continued and program experiments commenced in earnest. The new station was not capable of competing favorably with the more powerful and very extensive facilities used by others, particularly those of foreign countries. During the past few years, in addition to station WCBX, located at Wayne, New Jersey, CBS has also programmed an affiliated 10-kilowatt international station, WCAB, formerly W3XAU, located near Philadelphia. These two stations will soon be replaced by the two 50-kilowatt stations now under construction. The new station call letters are WCBX and WCRC.

Engineering and economic studies, made to improve CBS short-wave facilities, began several years ago and have continued on to this date. They have now reached the stage where a large number of engineers are devoting full time to the subject. Facilities are being provided to improve greatly the service to Latin America and Europe. In addition to short-wave *broadcasting*, it is necessary that the new facilities be capable of *relaying* programs from New York to Mexico City, Buenos Aires, Rio de Janeiro, Santiago, Bogota, Lima, Havana, and other distant cities. This requirement has a great deal to do with planning, for instance, with the number and arrangement of directive antenna arrays.

In general, it has been necessary to select an adequate transmitting site and location; to have a sufficient number of transmitters of adequate power; to have available for use, one or more frequencies in each of the bands assigned to international broadcasting, 6 to 6.2, 9.5 to 9.7, 11.7 to 11.9, 15.1 to 15.35, 17.75 to 17.85, and 21.45 to 21.75 megacycles, by world radio allocation agreements as consummated at the most recent Telecommunications Conference held at Cairo, Egypt, in 1938. Stations WCBX and WCRC will operate on one or more frequencies in each of the bands. It was also necessary to decide upon the design of the transmitting equipment which, from a continuity and dependability of operation standpoint, must be arranged with a maximum degree of flexibility and capable of rapid changes in operating frequency. As

[1] "The Empire Short-Wave Station—Daventry" and "Receiving the Empire Station," British Broadcasting Corporation publications, 1939.
[2] Philip L. Barbour, "Open questions in inter-American broadcasting," *Annals Amer. Acad. Pol. and Soc. Sci.*, vol. 213, pp. 116–124; January, 1941.
[3] William S. Paley, "Radio turns south," *Fortune*, vol. 23, pp. 77–79, 108, 111–112; April, 1941.

mentioned previously, the necessary number and type of directive antenna arrays had to be selected to fulfill transmission requirements best.

WCBX-WCRC New Facilities

In addition to the thirty CBS studios now located in New York City, new studios are being constructed to serve the new international stations. The most modern studio construction practices known to the broadcast art will be utilized. The audio facilities will be designed and operated in accordance with standard CBS practice.[4]

From the new studios, programs will be sent to the WABC master control, located on the twenty-third floor of the Columbia Building. From this point, they will be transmitted to three 330- to 340-megacycle frequency-modulation radio relay transmitters located on the roof of the sixty-two story Salmon Tower Building. These transmitters will excite unidirectional antennas, each having a gain of 10 decibels or more in the direction of Brentwood, Long Island, New York.

Similar antennas, for receiving purposes, will be used at Brentwood. Special receiving, amplifying, and other control equipment, will be used to demodulate the signals and transmit them to the main transmitter building located about one mile from the receiving site. Due regard has been given to the proper location of both transmitting and receiving equipment for optimum results. This proposed operation is experimental in nature and will allow CBS engineers to pioneer in this high-frequency relay broadcast field. The performance of this system must be stable, completely reliable, and suitable for continuous operation over long periods of time.

[4] H. A. Chinn, "Broadcast studio audio-frequency systems design," Proc. I.R.E., vol. 27, pp. 83–87; February, 1939.

The Brentwood Installation

Through special arrangements with the Mackay Radio and Telegraph Company, the site of their Brentwood main transmitting plant will be used, where there are now already in operation twenty-two medium- and high-powered radiotelegraph transmitters. Mackay is now using many directive antenna arrays on their 1200-acre site which, for short-wave transmission, is excellent from the standpoint of topography, accessibility, and availability of public-utility services. It is removed from populous centers, airports, and airways.

A new fireproof, single-story wing, 40×60 feet, with basement, is now being added to the existing Mackay transmitter building, to house the new equipment.

Primary power supply is available from two different sources over alternate routes to the Mackay-CBS substation, from which three underground, 2300-volt cables run to the transmitter building, a distance of 0.66 mile. The three power feeders have a combined capacity of 1800 kilovolt-amperes.

Audio, measuring, and monitoring facilities have been designed by Columbia's engineering staff and include the very latest methods of satisfying the requirements of this project. The basic principles that must be considered in the functional design of a modern two-channel transmitting plant's audio and monitoring system will be used. Because of the nature of this service, the frequency- and modulation-monitoring apparatus arrangement, Fig. 1, is more complex than that usually found at standard broadcast stations.

Compression of volume range, modulation "peak-chopping," high-frequency pre-emphasis, and variable low- and high-pass filters, will be available to obtain optimum results. The degree of their use will depend upon transmission conditions and other variable factors.

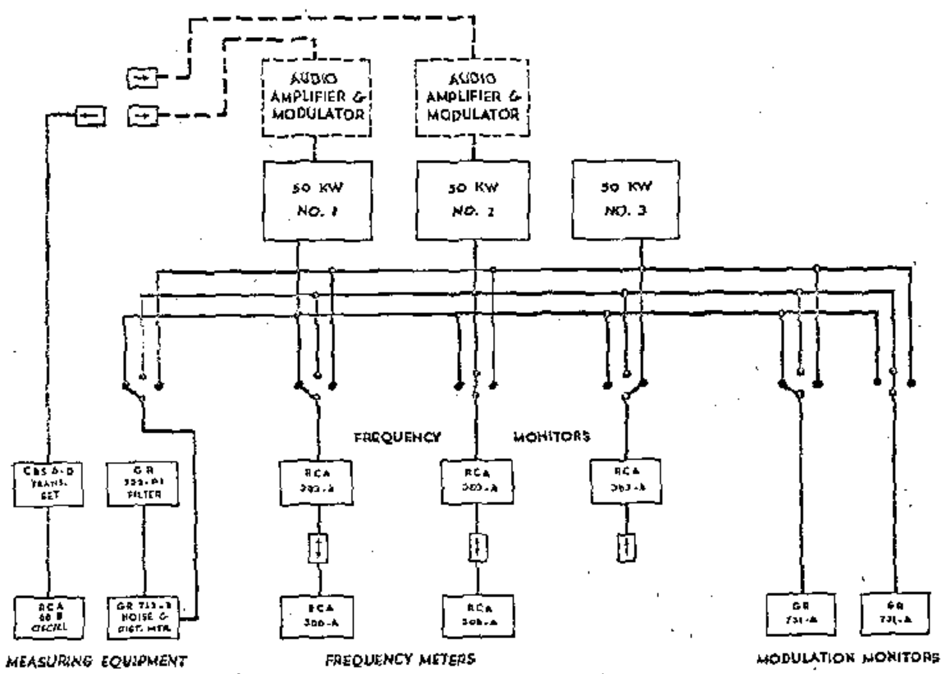


Fig. 1—Block diagram of the WCBX-WCRC monitoring facilities.

Transmitters

Two custom-built, 50-kilowatt international-broadcast-station equipments of the latest design, conceived three years ago, are now being manufactured for this installation by the Federal Telegraph Company. These facilities are being constructed in accordance with specifications originated by the engineering department of CBS. Each of the two transmitters will be capable of full output power to the transmission line, at 100 per cent modulation, over the entire frequency range of 6 to 22 megacycles. It has been possible only recently to obtain such powers in practice at the higher radio frequencies.

One of the major requirements of this service is the ability to shift instantaneously from one operating frequency to another. These transmitters are designed so that this can be accomplished in a simple, positive, and reliable manner. There are several methods of accomplishing this operation.[5] CBS engineers chose the method to be described after carefully weighing the advantages and disadvantages of various systems.

In order to accomplish an instantaneous change in frequency, there are provided three complete radio-frequency sections from the crystal-oscillator unit to the 50-kilowatt power-amplifier output. Fig. 2 is a block diagram illustrating the arrangement of all major apparatus units. This system allows the technicians who operate the apparatus to preset the operating frequency of one radio-frequency section while the other two radio-frequency sections are being operated simultaneously.

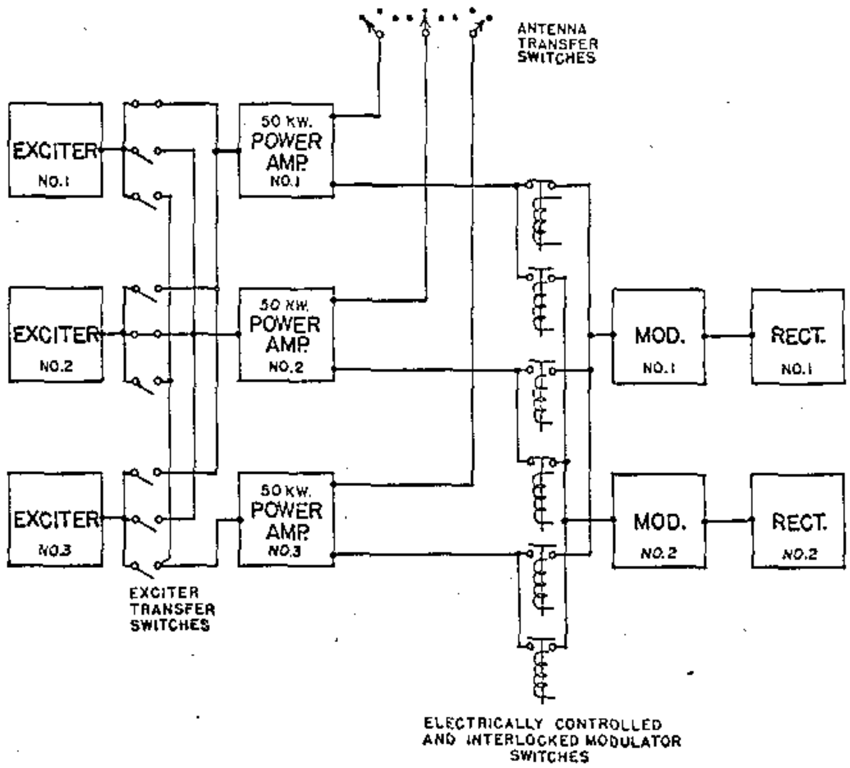


Fig. 2—Block diagram of the WCBX-WCRC power amplifier and modulator selector system.

Each transmitter will be capable of operating on any one of a total of twelve frequencies. Initially, nine crystals will be provided for the frequency control of each radio-frequency section, a total of twenty-seven crystals being required for the specific frequencies assigned to WCBX and WCRC, 6060, 6120, 6170, 9650, 11,830, 15,270, 17,830, 21,520, and 21,570 kilocycles.

Actually, the apparatus for these two stations will consist of two and one-half transmitters. All of the radio-frequency equipment with associated power supply and control facilities will be provided in triplicate, and the high-level class AB modulators and high-voltage power supplies in duplicate. Thus the two stations may be expanded by the addition of a third modulation and power-supply unit which, with accessories, will give CBS a third complete 50-kilowat transmitter, should a third station be required at some future date. The equipment will be installed to accommodate this probable future expansion.

The entire equipment is alternating-current-operated, utilizing specially designed water-cooled tubes, automatically regulated power supplies, and with all circuits fully protected automatically. The apparatus is arranged so that complete accessibility to the interior of the transmitter units is provided for ease of maintenance, thus insuring maximum continuity of service. The operating personnel is safeguarded in every respect.

Performance characteristics will be in accordance with the most modern and best practices known to the art of broadcasting. They conform, in every respect, with the standards of good engineering practice promulgated by the Federal Communications Commission.

TABLE I
Transmitter Performance Specifications

Carrier frequency range	6 to 22 megacycles
Carrier power 6 to 22 megacycles	50 kilowatts
Modulation capability	100 per cent
Audio-frequency response	
40 to 10,000 cycles per second (1000 cycles per second reference)	±0.5 decibel
Audio-frequency distortion	
Root-mean-square total harmonics—100 per cent modulation—50 to 7500 cycles per second	Less than 5 per cent
Carrier noise level	
Root-mean-square total, unweighted (100 per cent modulation reference) 100 to 5000 cycles per second	−60 decibels
Below 100 and above 5000 cycles per second	−50 decibels
Carrier shift	
0 to 100 per cent modulation	Less than 3 per cent
Carrier frequency stability	Within ±0.0025 per cent

Circuits are conventional in design for the most part. There are a few noteworthy departures, including the line-type tank-circuit arrangement of the power amplifiers, the method of matching the power-amplifier outputs to the transmission lines, and the arrangement for multifrequency operation.

A water-cooled "resonating frame" type of line output circuit will be used with each of the three 50-kilowatt power amplifiers. It consists of a copper pipe from each anode parallel to each other for a lineal distance of

[5] R. J. Rockwell and H. Lepple, "A push-button-tuned 50-kw. broadcast transmitter," *Elec. Eng.*, vol. 60, pp. 55–57; January, 1941.

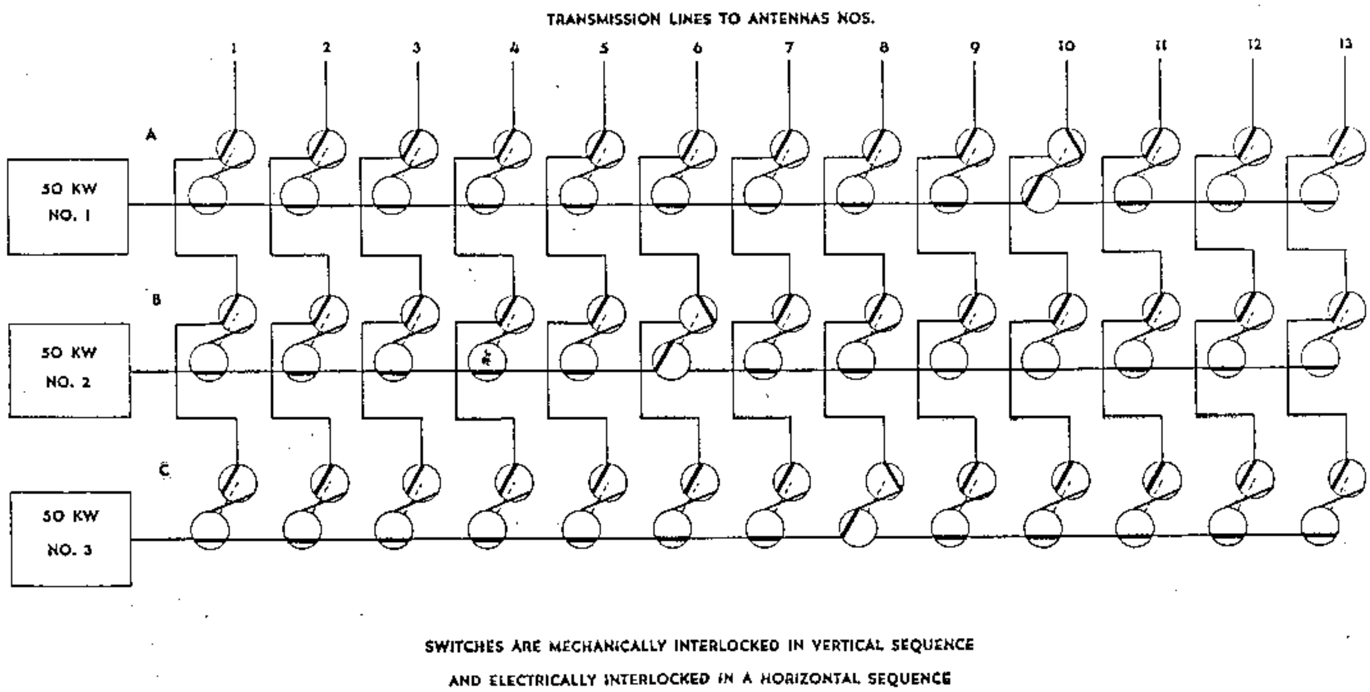


Fig. 3—The WCBX-WCRC antenna-switching system.

about 35 feet with a center-to-center separation of 12 inches. This length is required for 6-megacycle operation. The piping will extend directly below the tubes through a hole in the floor to the basement and there extend horizontally in a shielded interlocked compartment.

Inductive coupling will be used between the output circuit of the final stage and the line to the antenna-switching system. Mechanically this will consist of a transmission-line (or frame) loop mounted in a horizontal plane directly above, and running the full length of the tank-circuit frame. This coupling loop will be electrically grounded directly at its center.

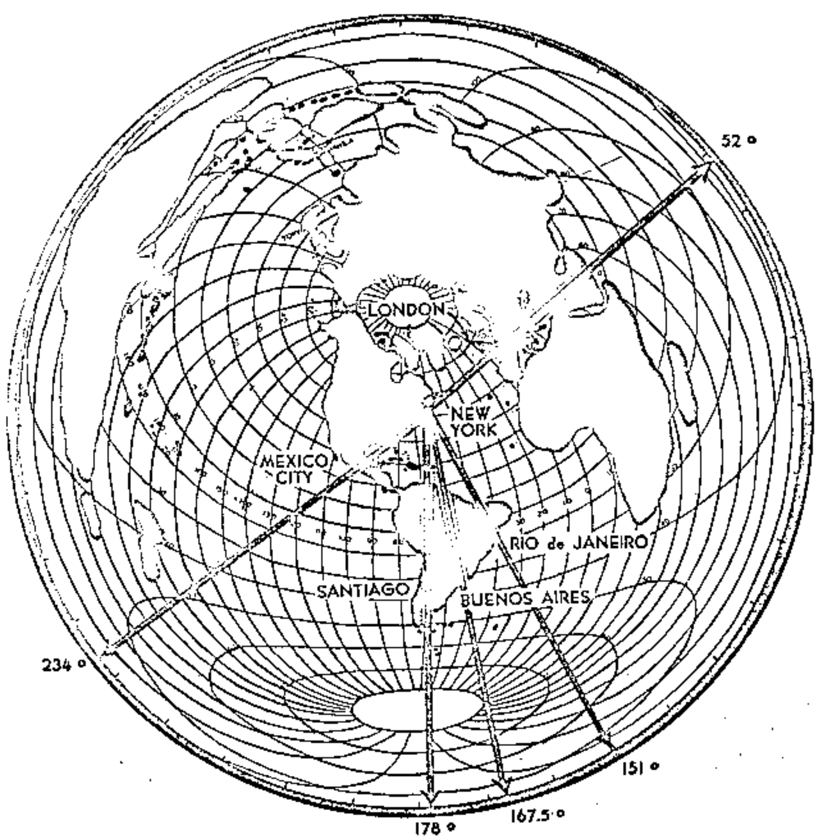


Fig. 4—An azimuth chart centered on New York City.

Variation of coupling will be accomplished by mechanically varying the horizontal distance between the two conductors forming this loop. This movement will carry them from a point directly above the individual lines of the tank frame, toward each other until they are but 2 or 3 inches apart. Thus the coupling is decreased, both by moving the coupling-loop conductors away from the tank-frame conductors and by decreasing the area within the coupling loop. The distance between the horizontal plane in which the tank-frame conductors are located and that in which the coupling-loop conductors are located will remain constant.

The movement of these conductors will be manual by means of a large handwheel crank located on the front panel of the power-amplifier unit and mechanically coupled with the mechanism controlling the position of the coupling-loop conductors.

Tuning the tank frame to a particular frequency will be accomplished by varying its length by means of a short-circuiting bar, the position of which may be continuously varied along the full length of the tank frame. This short-circuiting bar will

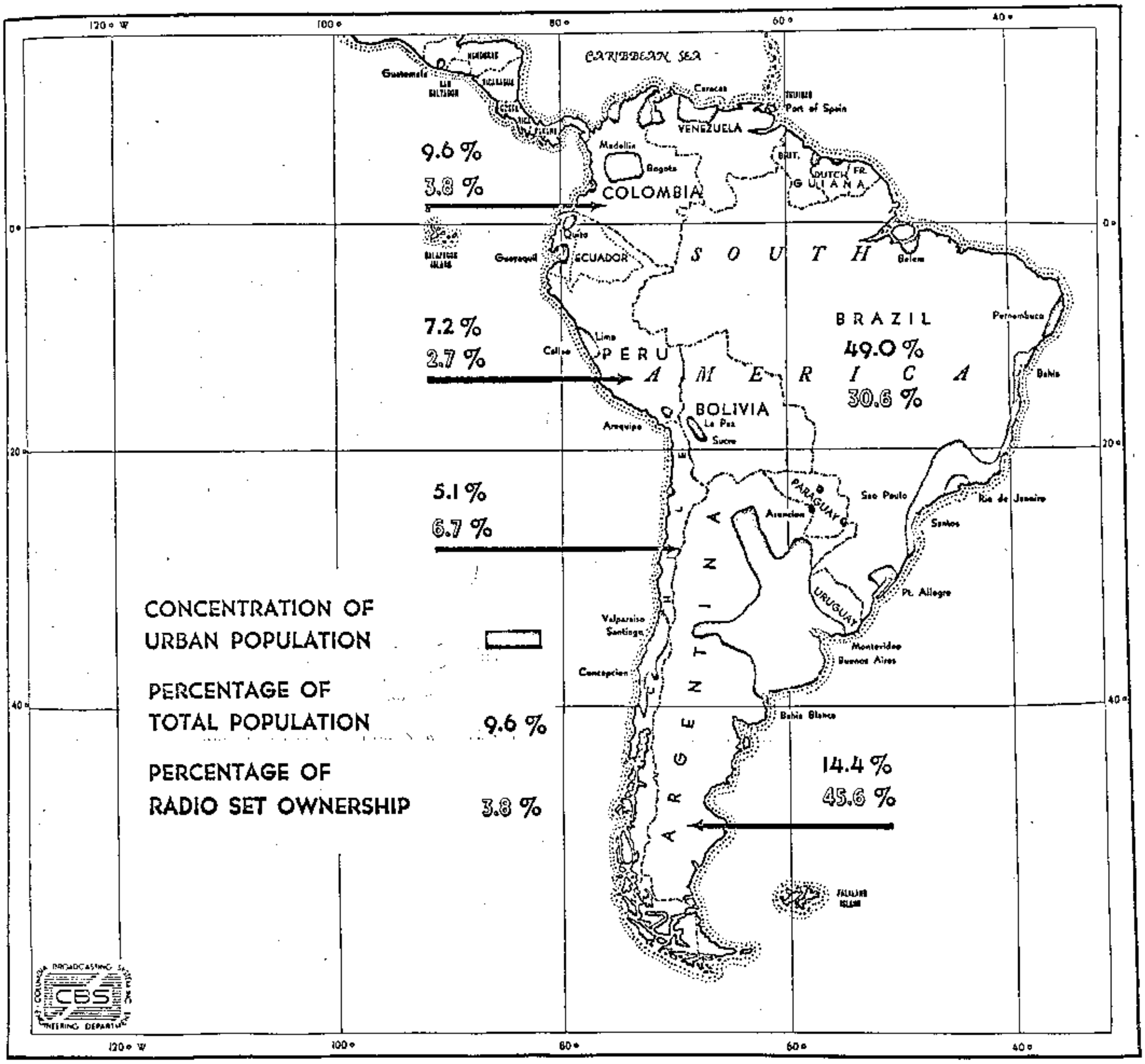


Fig. 5—Population density and radio-set ownership map of South America.

consist of suitable sliding contacts, arranged to grip the line with sufficient pressure, with the short-circuiting conductor between them. This arrangement will be carried on standoff insulators mounted on a traveling carriage moving on tracks below the line.

A large threaded shaft or worm approximately 2 inches in diameter will be located at the center of and below the line, supported by bearings spaced approximately 4 feet on centers. This worm extends the full length of the line and the carriage (with short-circuiting bar) is attached to it by a nut (split on one side to pass the bearing supports) of sufficient length to ride over the receded bearings. Thus the position of the carriage can be controlled by rotation of the worm.

At the end of the line, away from the power-amplifier unit is located a 3-phase, reversible, 2-speed motor, which drives the worm by a V-belt coupling. At the end of the line near the power-amplifier unit a flexible shaft is attached to the worm and this is used to drive a counter, on the front panel, so that the exact position of the carriage can be read on the counter.

To select any one of the six frequency bands the carriage will be run at high speed as follows: A 6-position rotary selector switch on the power-amplifier panel is set to the position desired and a motor-starting button pressed. Six "position" switches located along the carriage track may be placed at any location to determine the operating positions for the six frequencies. The rotary selector switch, in selecting one of these switches, determines the direction in which the motor must turn and pressing the motor-starting button closes the contactor to run the motor (at high speed) in that direction. When the carriage arrives at

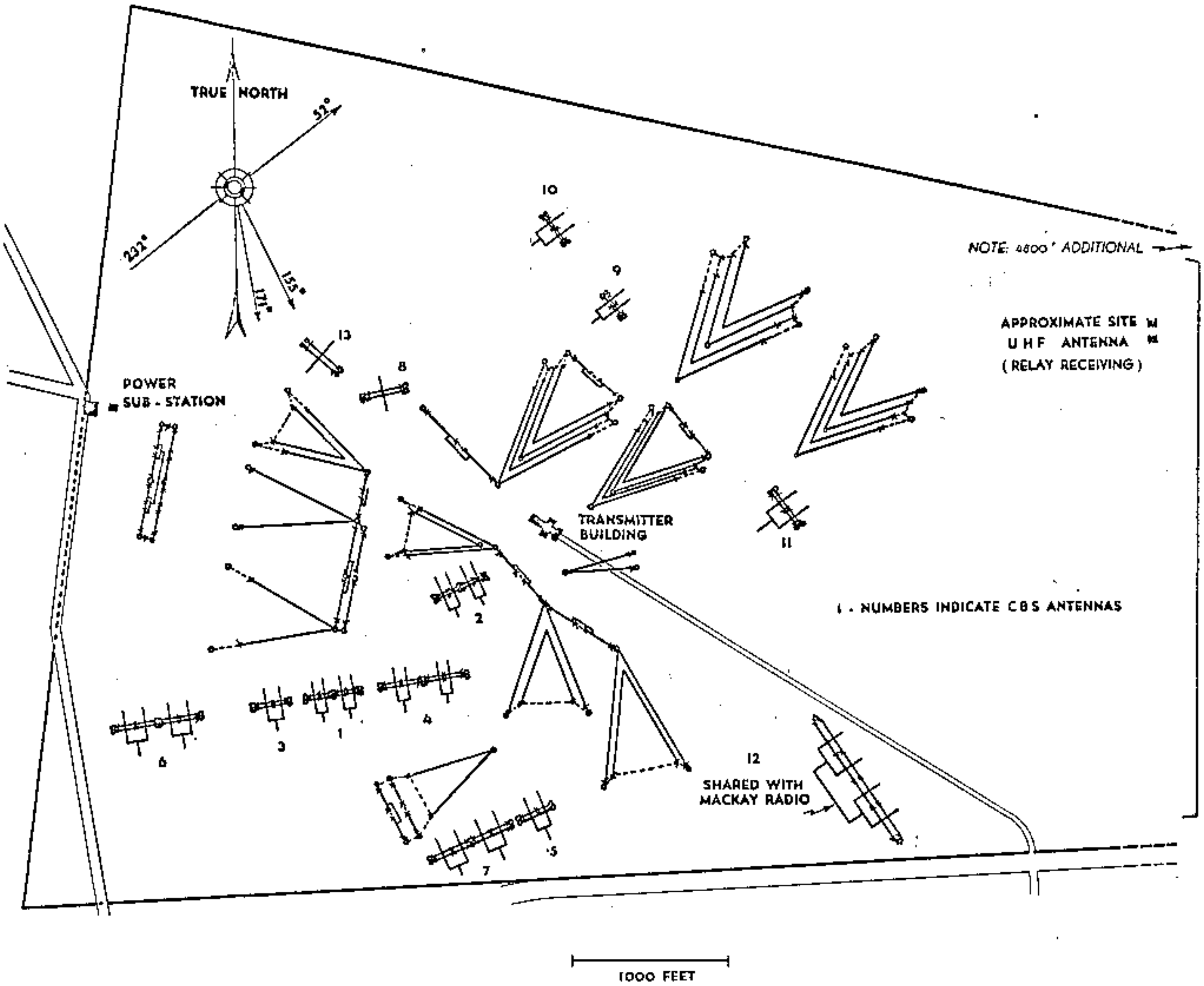


Fig. 6—Ground plan of CBS and Mackay antenna arrays, Brentwood, Long Island, N. Y.

the "position" switch selected and operates it, the contactor falls out and the motor stops.

A pilot light on the panel lights during the time the motor is running to show the operator the change is being accomplished. An interlock relay prevents 12-kilovolt plate voltage being applied to the amplifier during the process.

Safety limit switches are located at each end of the line to cut the motor and prevent damage in case one of the "position" switches fails to stop the travel. These limit switches have associated pilot lights on the power-amplifier panel to inform the operator of the miscarriage. Pressing the start button will bring the carriage back from the end of the line to a selected position without the necessity of going into the basement to run the mechanism by hand.

Vernier adjustment of the carriage position is accomplished by a nonlocking, spring-return, single-pole, double-throw, manual switch on the power-amplifier panel which operates contactors to run the carriage in either direction at slow speed (actually half speed); this adjustment may be made with power on. The manual slow-speed control of the motor is independent of the high-speed position-selecting control except that interlocking contacts prevent their being operated at the same time.

A second pair of pipe lines will also connect to the power-amplifier anodes and run parallel to the pipes just described, but will be enclosed in a separately shielded compartment. This line circuit will be short-circuited at the proper point to resonate it with the fundamental frequency. A fifth pipe will run between this short-circuited pair to provide a path to ground for the even-order harmonics and thus result in more efficient operation of the power amplifier. The short-circuiting bar for adjusting the length of the harmonic-attenuation line has an identical control system to that of the output tank-circuit line. The rotary selector switch and starting button are common to both sets of lines so that one operation serves for both setting the output tank and the harmonic lines.

Voltage regulators, power transformers, modulation transformers, reactors, and other associated equipment will be located in a basement directly beneath the apparatus with which they are associated.

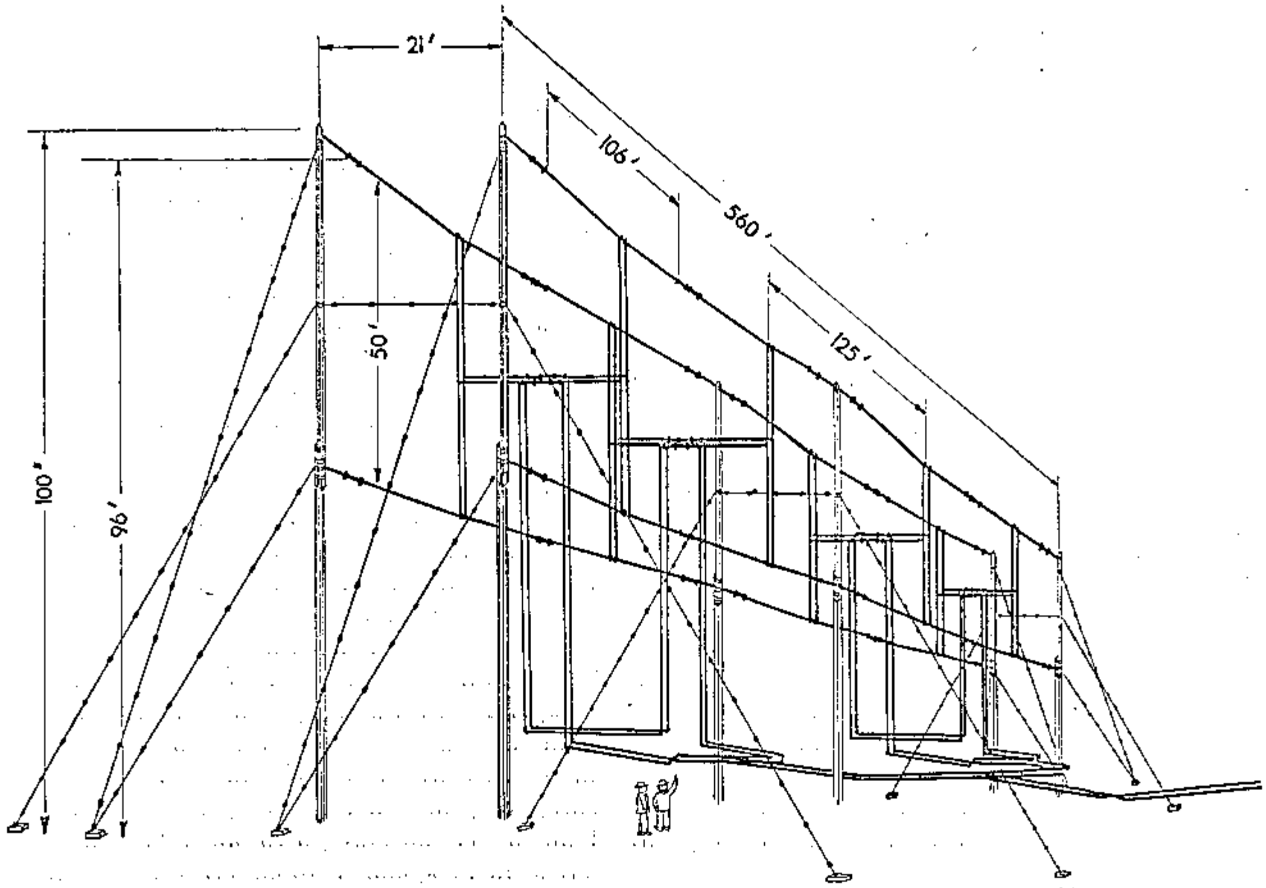


Fig. 7—WCBX-WCRC antenna No. 7 (9650 to 11,830 kilocycles) 4-section horizontal broadside array.

Transmission Lines

One of the major considerations is the switching facilities to be used for interconnecting any of the three 50-kilowatt-amplifier output lines with any desired combination of the thirteen transmission lines. Thirty-nine specially designed switches are required for this purpose. Fig. 3 illustrates the system to be used. These switches, manually operated, will be interlocked mechanically and electrically, in order to insure proper operation and protection to apparatus. As the voltage on the lines will be high during peaks of modulation (14,000 volts, root-mean-square) special insulators with properly designed fittings must be used. This is also true of the transmission-line and antenna insulators, all of which have been designed for operation at 400 kilowatts peak power, at 22 megacycles, with a liberal safety factor included. These switches are so arranged as not to unbalance the impedance of the lines, and thus reduce to a minimum loading difficulties, reflection losses, and undesired radiation. Voltage-breakdown tests have been made to determine the comparative merits of various insulator designs when operated at high voltages under practical operating conditions.[6]

More than 100,000 feet of copper wire will be used for the open 2-wire balanced transmission lines. Each of the lines will have a characteristic impedance of about 550 ohms. It is interesting to note that 20 tons of No. 0 B & S gauge copper wire will be required for the transmission lines and antenna elements, supported from 536 wooden poles and 10 steel towers. This gives one a general idea of the scope of the antenna system.

Special networks will be installed on the transmission lines for the purpose of performing a variety of services, including the matching of impedances, the control of phase relationships, the division of power, filter action, the filtering of harmonic frequencies, and the simultaneous transmission of two frequencies over one transmission line.

Some of the functions of these networks could be carried out using lumped inductance and capacitance, but it has been found more practical to utilize networks made of sections of transmission line of the same construction as the feeders themselves. The latter are preferable mechanically and economically, not only because they are more rugged and stable when exposed to the elements, but also because their performance may be calculated with a greater accuracy. The parameters on which their electrical properties depend are linear dimensions which may be measured on the job, in feet and inches, more simply and more accurately than the inductance of a coil or the capacitance of a condenser could be measured under similar circumstances.

Some of the networks that will be used are known

[6] Andrew Alford and Sidney Pickles, "Radio frequency high voltage phenomena," *Elec. Eng.*, vol. 59, pp. 129–136; March, 1940.

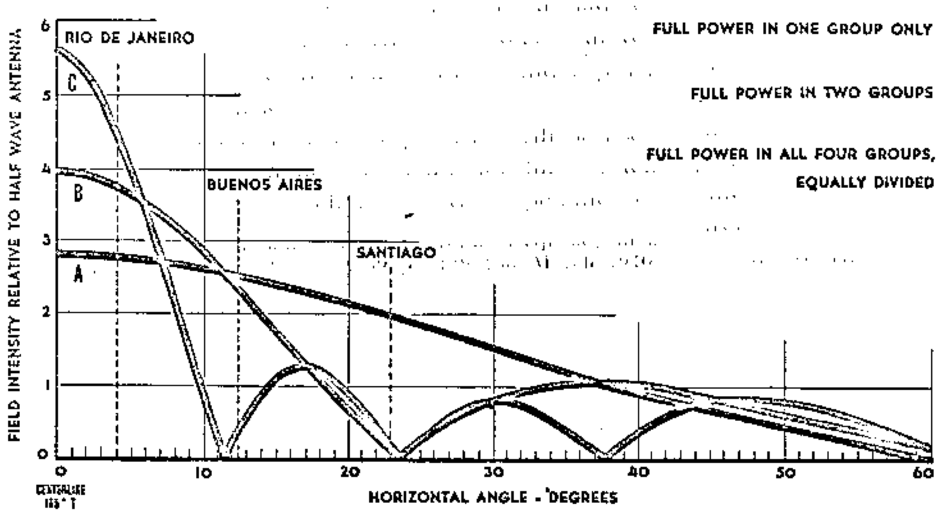


Fig. 8—The horizontal radiation characteristic of antenna No. 7 (9650 kilocycles).

as the "re-entrant" type, which consist of two sections of transmission line joined at their ends in such a way as to form a closed loop.[7]

It will be necessary to use conjugate sections on the transmission lines. Two sections are conjugate when the standing-wave (E_{max}/E_{min}) voltage ratio created on a flat line by one section is corrected by a second section, so that a given frequency is passed without change of voltage ratio.

A further and more important use of conjugate sections is to employ them in two pairs, the first pair passes frequency F_1 without introducing a ratio, but is so designed as to introduce a predetermined ratio for frequency F_2 for the purpose of matching the line to the load. The other pair passes frequency F_2 without change of line ratio, but matches impedances for frequency F_1. Thus, the line will be matched to the load for two frequencies simultaneously and permits one antenna to be fed with either one of the two frequencies, or by the two simultaneously, if a suitable line input network is employed to isolate the lines from each transmitter properly.

One of the antennas for transmission to Europe will be used simultaneously by CBS and Mackay, the former using 6120 kilocycles and the latter 6935 kilocycles. The first is a modulated 50 kilowatt carrier and the second a 50-kilowatt continuous-wave carrier.

A re-entrant 2-stage conjugate filter will be used to isolate the two transmitter output circuits and to maintain proper impedance relationships between the power-amplifier outputs and the line that feeds the antenna array.[7,8] A network of this type consists of four filters. Two on one side of the network are designed to block frequency 6935 kilocycles. The other two filters on the opposite side of the network block frequency 6170 kilocycles. The first two filters are conjugate at frequency 6170 kilocycles while the other two are conjugate at frequency 6935 kilocycles.

These networks will be installed near the transmitter building in order that only a single long transmission line will be required to carry the two frequencies to the antenna. This feeder is about 3800 feet long. The economic advantages are obvious as this plan eliminates the requirement of two separate long transmission lines and two separate antenna arrays.

Several of these networks have been successfully used by Mackay at Brentwood. Their use has been entirely trouble-free and excellent constancy of adjustment has been obtained with a minimum of maintenance attention.

Experience has shown that a 5 per cent separation between frequencies of two transmitters is sufficient for satisfactory operation of these networks. The degree of filtering obtainable under these conditions is such that the attenuation of the undesired frequency amounts to about 40 to 50 decibels. The power loss is not more than 0.2 to 0.3 decibel.

Directive Antenna Arrays

The engineering, mechanical, and economic considerations affecting the choice of directional antenna design were given detailed study by a group of engineers. After giving due attention to all service requirements, including direction, distance, and areas to be served, many plans were considered and one of these adopted.

Fig. 4, an azimuth chart centered on New York City, indicates the true bearings to the various world-wide areas proposed to be served. Fig. 5 shows the

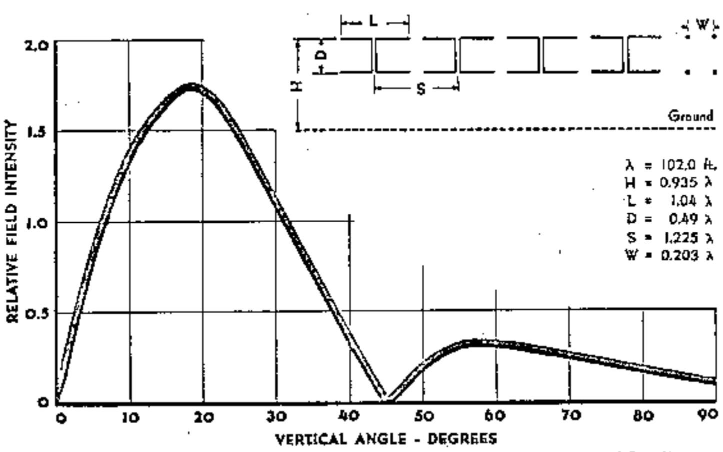


Fig. 9—The vertical radiation characteristic of antenna No. 7 (9650 kilocycles).

[7] Andrew Alford, "High frequency transmission line networks," *Elec. Comm.*, vol. 17, pp. 301–310; January, 1939.
[8] Andrew Alford, "Coupled networks in radio-frequency circuits," Proc. I.R.E., vol. 29, pp. 55–70; February, 1941.

concentration of urban population and receiving sets in South America.

These, and other factors, resulted in the decision to erect, initially at least, 13 unidirectional arrays, 30 antenna-array—frequency combinations, in accordance with Table II.

The radiation characteristics of a directive antenna array of this, and other horizontally polarized types, depends upon the topography, arrangement, physical dimensions, number of elements, distance between the elements, distance between the radiator and the reflector, height of the elements above ground, the phase and distribution of the current, the magnitude of power in each of the elements, and the operating frequency.[9]

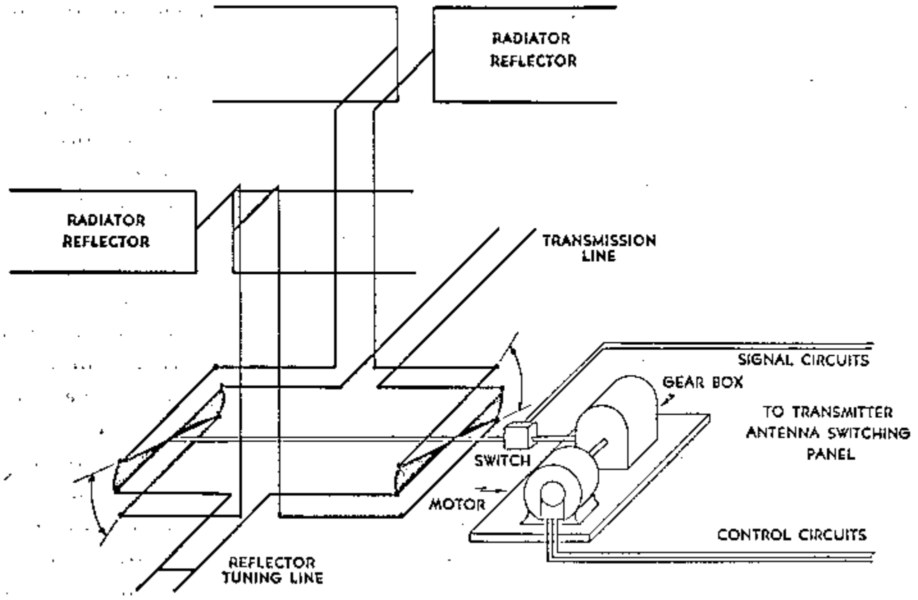


Fig. 10—WCBX-WCRC remote-control radiator-reflector reversing system used on antennas Nos. 9, 10, and 11 for transmission to Europe or Mexico—Central America.

The Brentwood antennas will consist of stacked horizontal broadside arrays, with parasitically excited reflectors. They comprise rows of 2, 4, or 8, 0.5 λ to 0.64 λ elements, placed side by side, in two rows stacked one above the other, with a vertical separation between rows of 0.50 to 0.64 λ. The reflector is 0.20 to 0.22 λ from the radiator. The height above ground of the bottom row of elements depends upon the frequency for which the antenna is designed and is usually more than 0.5 λ. Fig. 6 shows the arrangement of CBS and Mackay antennas on the Brentwood site ground plan.

Fig. 7, is a drawing of a typical array, antenna number 7, designed for operation on 9650 or 11,830 kilocycles, having a calculated gain of 15 decibels at the lower and 16 decibels at the higher frequency. Fig. 8 indicates the horizontal and Fig. 9 the vertical radiation characteristics of this array.

Field tests, with small-scale models, give results which corroborate the antenna-design calculations and thus, it is believed that anticipated performance will be realized in practice.

Reflectors are used to obtain an additional gain of almost 3 decibels in the forward or desired direction of radiation. This is equivalent to doubling the carrier power of the transmitter, with the added advantage of reducing backward radiation, which, on the higher frequencies, sometimes results in impairing the quality of reception due to echo effect. The signal, when radiated both forward and backward, arrives at the receiving antenna over two different great-circle paths of different lengths, thus producing this phenomenon. Echo sometimes arises, even when unidirectional radiation takes place, because of the signal arriving at the receiver once, and a second time, approximately $\frac{1}{7}$ of a second later, after it has traveled

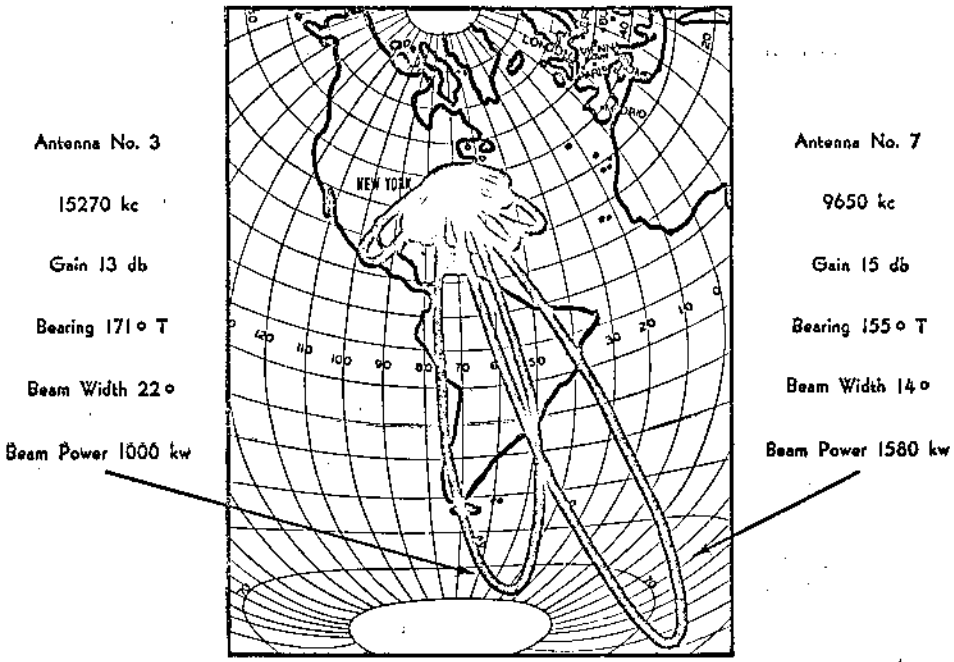
[9] G. C. Southworth, "Certain factors affecting the gain of directive antennas," Proc. I.R.E., vol. 18, pp. 1502–1536; September, 1930.

TABLE II

Directional Antennas to South America and West Indies

Antenna Number‡	Frequency Kilocycles	Direction True (E of N)	Beam Width (6 decibels down)	Vertical Angle (maximum radius)	Gain†	General Direction
		Degrees	Degrees	Degrees	Decibels	
1.	17830 21520 21570	171*	14 12	14 12	15 16	Argentina-West Coast South America
2.	17830 21520 21570	155*	14 12	14 12	15 16	Brazil-East Coast South America
3.	11830 15270	171*	30 22	18 14	11.5 13	Argentina-West Coast South America
4.	15270 17830	171*	14 12	17 14	15 16	Argentina-West Coast South America
5.	11830 15270	155*	30 22	18 14	11.5 13	Brazil-East Coast South America
6.	9650 11830	171*	14 12	18 16	15 16	Argentina-West Coast South America
7.	9650 11830	155*	14 12	18 16	15 16	Brazil-East Coast South America
8.	6060 6120 6170	166	41	18	10	South America
Directional Antennas to Europe or Mexico and Central America						
9.	[illegible]	52* or 232*	[illegible]	14 12	12.5 14	Europe or Mexico and Central America
10.	11830 15270	52* or 232*	30 22	18 14	11.5 13	Europe or Mexico and Central America
11.	9650 11830	52* or 232*	28 22	18 15	12 13	Europe or Mexico and Central America
12.	6060 6120 6170	54	14	18	15	Central Europe
13.	Same	220	41	18	10	Mexico and Central America

* Adjustable ± 10 degrees.
† Reference antenna 0.50λ horizontal dipole in free space.
‡ 30 antenna-array—frequency combinations.



HORIZONTAL RADIATION CHARACTERISTICS
(BEAM DIRECTION ADJUSTABLE ± 10°)

Fig. 11—Simultaneous transmission to Latin America from WCBX and WCRC.

all the way around the world and been received again.

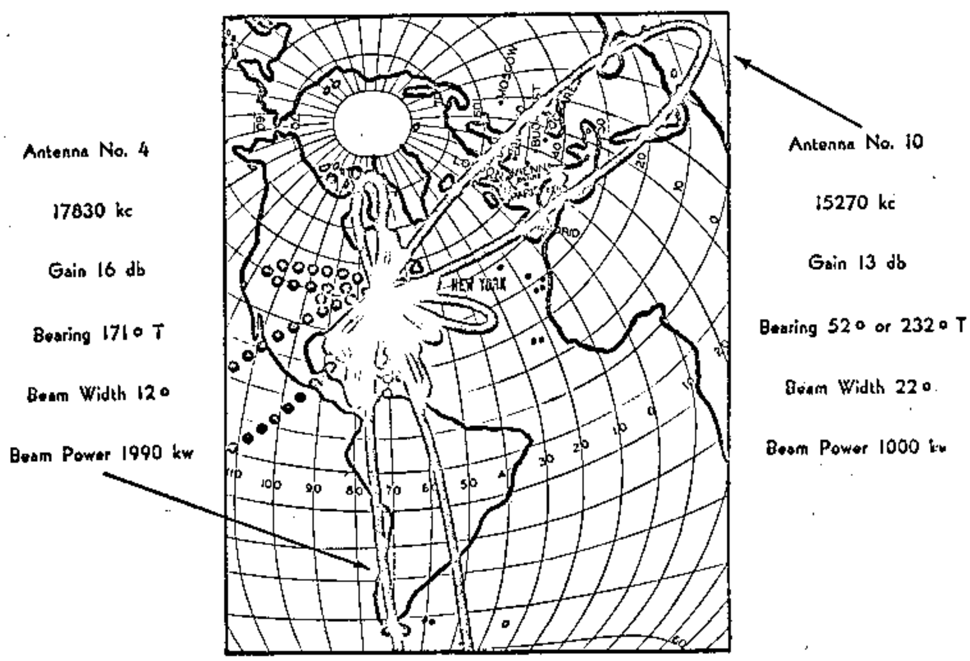
Three of the antennas, numbers 9, 10, 11, may be reversed 180 degrees by remote control, and used for transmission to Europe or to Mexico and Central America. This is accomplished by interchanging the transmission-line and reflector-line matching stub with the radiator and reflector, using two double-pole, double-throw switches, a switch for each section of the antenna. Two switches will be required for each of these reversible arrays. Fig. 10 indicates some of the details of this arrangement.

Figs. 11 and 12 show typical simultaneous transmission to various points of the world and represent typical combinations of antenna arrays as they will be used in practice. These are merely horizontal polar diagrams applied to an azimuth map centered on New York. The contours do not indicate coverage nor absolute field-intensity values but show the directions of maximum radiation.

The tuning and adjusting of the directive antenna arrays, with their associated transmission lines, is a complex task that requires the services of expert engineers who are experienced in this field and thoroughly familiar with the theory and measuring technique involved. Proof-of-performance data, based on field-intensity measurements, will be obtained at the Brentwood site, using as a reference antenna a 0.50 λ horizontal dipole located at various heights above ground. The array and reference antenna will be fed the same amount of power while rapid comparisons in performance are observed at the distantly located relay receiving stations. Empirical observations will also be made and these data evaluated. This subject is beyond the scope of this paper and will be treated in a future paper, based on the results of this work which will take many months to complete.

Operating Conditions

The best transmitting and receiving apparatus is of limited usefulness unless a number of frequencies are available for this service, at least one or more in each band. In general, the lower frequencies are good for night transmissions over paths of complete darkness, the higher frequencies for daytime transmission, and



HORIZONTAL RADIATION CHARACTERISTICS
(BEAM DIRECTION ADJUSTABLE ± 10°)

Fig. 12—Simultaneous transmission to Europe (or Mexico) and the West Coast of South America.

the intermediate frequencies, 15- and 11-megacycle bands, for transitionary periods of time; i.e., when the transmission path is partly in darkness and partly in daylight. Because several variable factors greatly influence the propagation characteristics of short waves, it is necessary to use the frequency best suited for an existing condition of transmission and upon the proper choice of frequency depends to a large degree the success or failure of a short-wave broadcast or relay.

The frequencies selected for daily operation, i.e., the station operating schedule, are determined by exhaustive study of (1) the United States National Bureau of Standards radio wave propagation data,[10] (2) field-intensity-measurement data, (3) professional reception reports such as those compiled by the British Broadcasting Corporation receiving station at Tatsfield, England, (4) frequency measurements made by the Union Internationale de Radiodiffusion Control Center, formerly located at Brussels and more recently located at Berne, Switzerland, (5) reports from CBS representatives abroad, and (6) correspondence from short-wave-station listeners.

The Union Internationale de Radiodiffusion Control Center frequency measurements are very useful for predicting sources of interference from other short-wave stations. They indicate, quite accurately, the number and identity of stations operating in each of the frequency bands. The 6- and 9-megacycle bands are exceedingly crowded at present resulting in considerable chaos and interference. It is hoped that with the conclusion of present unsettled conditions, world radio conferences will again convene, and this situation be improved. The recent inter-American radio conference held at Santiago, Chile, made noteworthy progress in this direction.

[10] T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, "Characteristics of the ionosphere at Washington, D. C.," monthly reports published in the Proc. I.R.E., vols. 25–29; 1937–1941.

International Receiving Station

It is necessary that the receiving-station facilities, the signals from which are used for rebroadcasting, be capable of performance equal to those of the transmitting station. Either space- or phase-diversity unidirectional antenna systems should be employed, and the entire receiving-station facilities properly engineered. A great deal of information has been published on this subject and will not be detailed here.[11,12,13]

Conclusion

The present and proposed service by international broadcast stations of North America, including expansion of existing facilities and construction of new stations, will undoubtedly accelerate interest in this service.[14] Transmissions from the United States to Latin American countries will soon be equal to or better than those now received from other countries. The new WCBX and WCRC transmitting stations will increase the intensity of CBS signals to Latin America and Europe, based on a conservative estimate, by at least 20 decibels. This is equivalent to a hundredfold increase in the power of the existing facilities.

Acknowledgment

Sincere thanks and appreciation are extended to Mr. Andrew Alford and associates of the Mackay Radio and Telegraph Company, and to my associates in the CBS General Engineering Department, for their cooperation and assistance in obtaining much of the material presented.

[11] A. A. Oswald, "The Manahawkin musa," *Bell Lab. Rec.*, vol. 8, pp. 130–134; January, 1940.

[12] J. B. Moore, "Recent developments in diversity receiving equipment," *RCA Rev.*, vol. 2, pp. 94–116; July, 1937.

[13] H. T. Friis and C. B. Feldman, "A multiple unit steerable antenna for short-wave reception," Proc. I.R.E., vol. 25, pp. 814–917; July, 1937; *Bell Sys. Tech. Jour.*, vol. 16, pp. 337–419; July, 1937.

[14] Raymond F. Guy, "NBC's international broadcasting system," *RCA Rev.*, vol. 6, pp. 12–35; July, 1941.