Wire Line Systems for National Broadcasting [1]

By A. B. CLARK

The interconnecting of radio broadcasting stations by special telephone lines for the simultaneous broadcasting of radio programs began on a commercial basis in 1923. Today well over 30,000 miles of program transmission circuits are in use in the United States and transcontinental broadcasts by means of such wire lines are a daily occurrence.

The paper first states the radio limitations which make wire lines necessary for broadcast coverage of large nations. A map and data are given showing the present broadcasting chains in the United States and indicating the extent of their use. An explanation is given of why program transmission circuits must have transmission characteristics materially different from message telephone circuits and a brief discussion of some of the important transmission characteristics of such circuits, including particularly "frequency range" and "volume range." The present chains in the United States which are made up almost entirely of open-wire circuits on a voice-frequency basis are briefly described. The manner in which these chains are tested and the way control is exercised are also indicated. To exercise this control requires an elaborate network of telegraph wires now aggregating over 40,000 miles and a corps of special men over 300 in number.

WHAT we are here considering, as an important factor in promoting national solidarity, is the tying together of a whole nation so that a single broadcast will instantly reach even the most remote points. Radio broadcasting stations (employing the more generally used frequencies) are essentially local distribution centers serving effectively points up to 50 miles (80 kilometers) or, in favorable cases, 100 miles (160 kilometers) or more from the radio transmitter. For the larger nations it is evidently necessary to make division into areas, locating a radio transmitter in each area for its coverage, and then to provide a network of circuits connecting the transmitters in the various areas with the point at which the broadcast originates. At the present time wire telephone systems are employed almost exclusively for this national distribution of broadcasts. It is the purpose of this paper to discuss the wire networks which are now being provided in the United States by the Bell Telephone System.

In the United States at the present time (January 15, 1929) programs are being regularly distributed over extensive wire networks or "chains" as indicated on the map of Fig. 1.[2] The various chains

[1] Presented before the World Engineering Congress at Tokio, Japan, October, 1929, Proc. of the I. R. E., November, 1929.

[2] This map has been revised to show the network chains as of September 1, 1929.

are usually referred to by colors and are so designated on the map. As a regular procedure most of these chains operate about six hours each day. Following are the numbers of radio stations served by each chain together with the lengths of telephone circuit involved. (An additional chain which operates only one hour each week is not included.)

	Radio Stations	Telephone Circuit Miles	
Red network [3]	41	10,500	16,600 kilometers
Purple network	41	8,450	13,600 "
Blue network	12	3,650	5,900 "
Green network	8	3,600	5,800 "
Orange network	5	1,700	2,700 "
Brown network	3	450	700 "
Total	110	28,150	45,300 "

[3] See table on Fig. 1 for revised data as of September 1.

On occasions when events of particular importance take place, several of the regular chains may be merged together and additional circuits added so as to pick up programs from various parts of the country. For example, on November 5, 1928, the evening before the United States presidential election, the networks shown in Fig. 2 were in operation, about 85 radio stations being included. At various times during this evening, five separate programs were broadcast from several different points in New York City; Palo Alto, California; Little Rock, Arkansas; and Pittsburgh, Pennsylvania. The United States was thus virtually one great auditorium, with listeners estimated as no less than fifty million.

From the technical standpoint, program transmission circuits are, of course, very different from message telephone circuits. In the first place, message telephone circuits must be arranged so that to and fro conversations can take place practically instantaneously. Program transmission circuits on the contrary are single-direction transmission circuits. They are, therefore, not complicated by problems of electrical echo, singing and the like, which are ever present with long message telephone circuits. However, although free from the problems of two-way working, the design and operation problems of program transmission circuits are by no means easy as compared with those of message telephone circuits. On the contrary, in many respects, these problems are considerably more difficult, the reason being that the requirement as to approach to absolute fidelity of reproduction is much more severe than for message telephone circuits.

A frequency band width of 2,500 cycles furnishes, if properly utilized, a telephone circuit over which speech is transmitted very clearly so that conversations may be easily carried on. This band is not

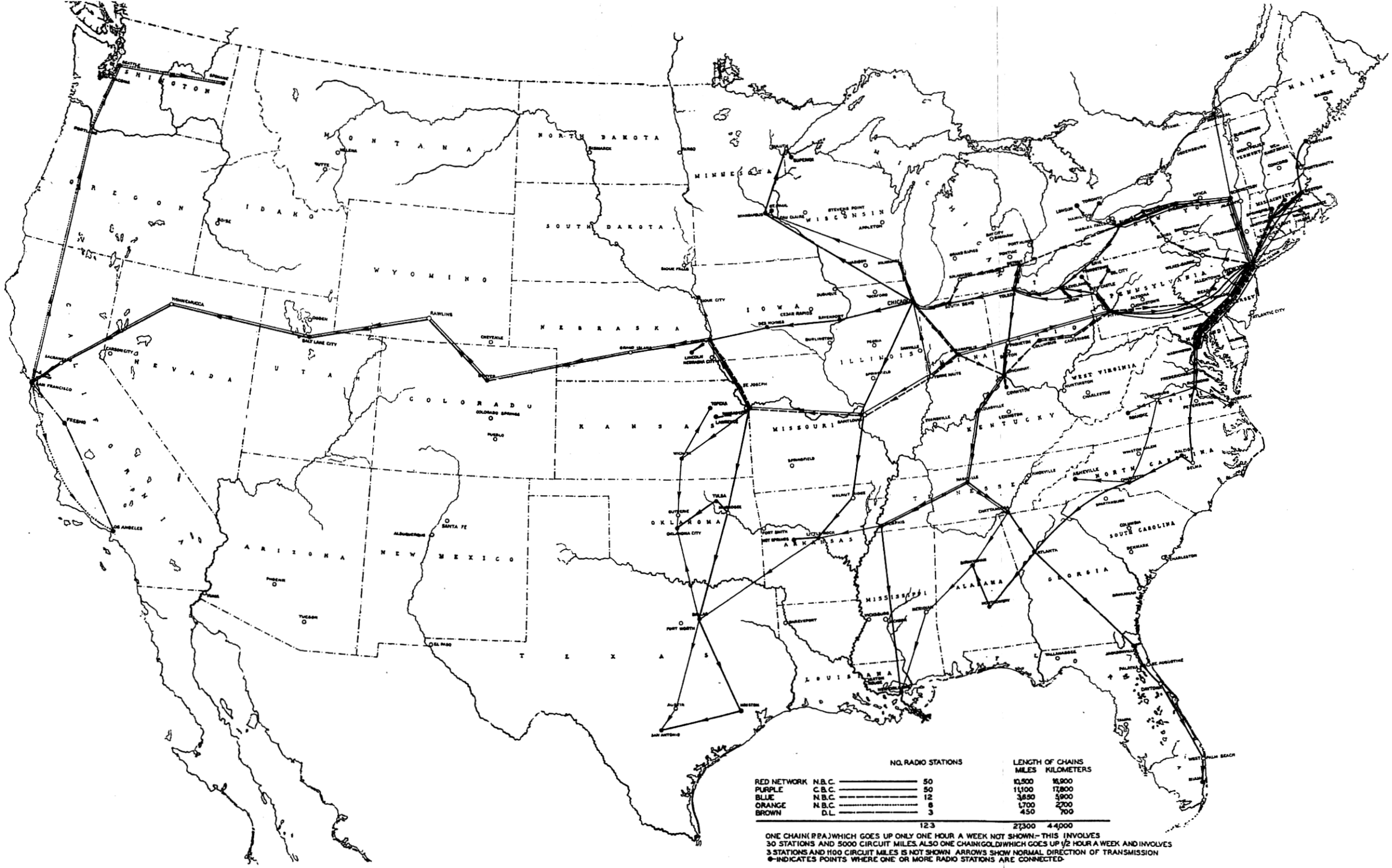

Fig. 1—Routes of Bell System Program Network Chains in the United States as of September 1, 1929.

the amount of distortion which theory and experience indicate should be expected. Then, final adjustments are made by certain specially provided adjustable parts in accordance with the overall measurements. Such overall tests and adjustments are, in general, made daily.

In setting up these circuits, another important consideration is that each amplifier carry its proper load or, in telephone parlance, each amplifier deliver to its associated line the proper output level. To insure this, diagrams are prepared in advance, showing the desired transmission levels at each repeater, a typical diagram being shown in Fig. 3. In setting up the circuits, the repeater gains are first set

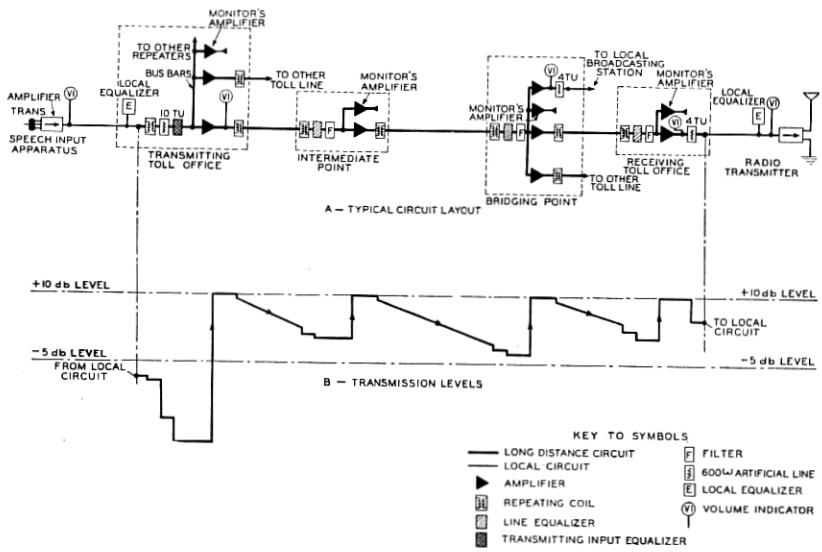

Fig. 3—Typical Circuit Layout and Transmission Level Diagram of Program Network Circuits.

to values which theory and experience indicate should result in conditions as shown in the prescribed transmission level diagram. Testing current is then applied to the sending end of the circuit and sensitive measuring devices are applied at the output of each repeater. If the results of these measurements do not accord with the transmission level diagram, suitable adjustments are then made.

In building up the large chains which tie together a considerable number of radio transmitters, wire distributing centers are provided at strategic points. Figure 4 shows the circuit layout of the various chains which have been referred to and indicates in a general way how

produce an undue amount of disturbance in neighboring circuits which may be transmitting other programs or telephone messages. The designer is also concerned lest when the program power is weak the programs be unduly interfered with by noise or crosstalk from other circuits. He must particularly consider the noise and crosstalk which may be heard during pauses in programs. During such pauses it is very annoying to the listeners to hear a background of noises of various sorts and it is essential that the listeners be unable during such pauses to pick up intelligible speech from telephone message circuits crosstalking into the program circuit.

At the present time generally satisfactory results are being obtained in transmitting the volume range of about 30 decibels (3.4 nepers). Considerably more must be done both in the radio and in the wire systems, however, before there can be transmitted volume ranges comparable with those put out by symphony orchestras, high-grade artists, and the like.

Having indicated in a general way the requirements of program transmission circuits, there will next be described the wire systems which are now in use in the United States.

The present-day program transmission circuits in the United States are "on a voice-frequency basis," which means that the waves transmitted over the circuits are essentially copies of the sound waves impinging on the microphones. Most of the circuits now being provided are carried by the familiar open wires, usually copper wires 0.165 inch (4 mm.) in diameter spaced about 1 foot (30 cm.) apart on the crossarms. The transmission properties of an open-wire pair without loading are well suited for program transmission purposes since the distortion is comparatively small although it is far from negligible. Spaced at intervals on these circuits, averaging roughly 150 miles (240 kilometers) apart, are one-way repeaters or amplifying devices. Along with these amplifiers are other electrical devices for counteracting the distortion introduced by the open-wire circuits, incidental cables involved, etc. Other one-way repeaters are provided at the terminals of the circuit. Considerable technical refinement is, of course, involved in the design of these amplifiers and of the auxiliary apparatus associated therewith which cannot be gone into here.

In setting up the program transmission circuits, an important part of the work consists in making measurements at different single frequencies within the band which it is desired to transmit over the circuit. Before making such overall measurements, the amplifiers and auxiliary apparatus are so adjusted locally as to compensate for

adequate, however, for program transmission because of the different character of the transmitted material. The bulk of present-day broadcast programs consists of musical selections, including a fair amount of high-grade material. To reproduce music, and particularly high-grade music, in a pleasing manner calls for a materially widened band. This wider band also gives a high degree of naturalness to speech which is particularly desirable when loudspeakers are used for reception.

At the present time in the United States the frequency band which is transmitted over the long distance program chains extends from about 100 cycles to about 5,000 cycles. It is, of course, possible to transmit an even wider band than this, although the cost of the circuits will, of course, increase as the band is widened. In considering how wide the band should be, the complete system, including pickup apparatus, wire transmission line, radio transmitters, radio transmission paths through the ether, radio receiving apparatus and loud speakers must be considered. It seems probable that as the art progresses a band wider than the above will be found desirable. On the wire line systems, development work is going forward looking toward the possibility that such wider bands may be found desirable in the future. At the lower frequencies, where most people consider that improvement is particularly desirable, consideration is being given to the possible extension of the band down to 50 cycles and possibly lower. Consideration is also being given to the possible addition of two or three thousand cycles to the top of the band.

In addition to this broad band transmission requirement, program transmission circuits must be designed to handle wide ranges of volume, particularly for the transmission of musical programs. Much of the enjoyment in listening to good music appears to come from the ranges of volume, so that in order to deliver such musical programs properly these ranges of volume must be preserved in large part at least. At the present time the volume ranges are "compressed" somewhat by adjustment of amplification under control of an operator at the pickup point. This tends to make easier the radio transmission problem as well as the wire transmission problem. The range of volume which is now delivered, as read by a "volume indicator" (a meter which roughly indicates the peaks), is of the order of 30 decibels (3.4 nepers), which means that during the fortissimo parts of programs the power which is transmitted is about 1,000 times as great as it is during the pianissimo portions.

The designer of the wire circuits must be concerned lest during those periods when the program power is strong, the program circuits

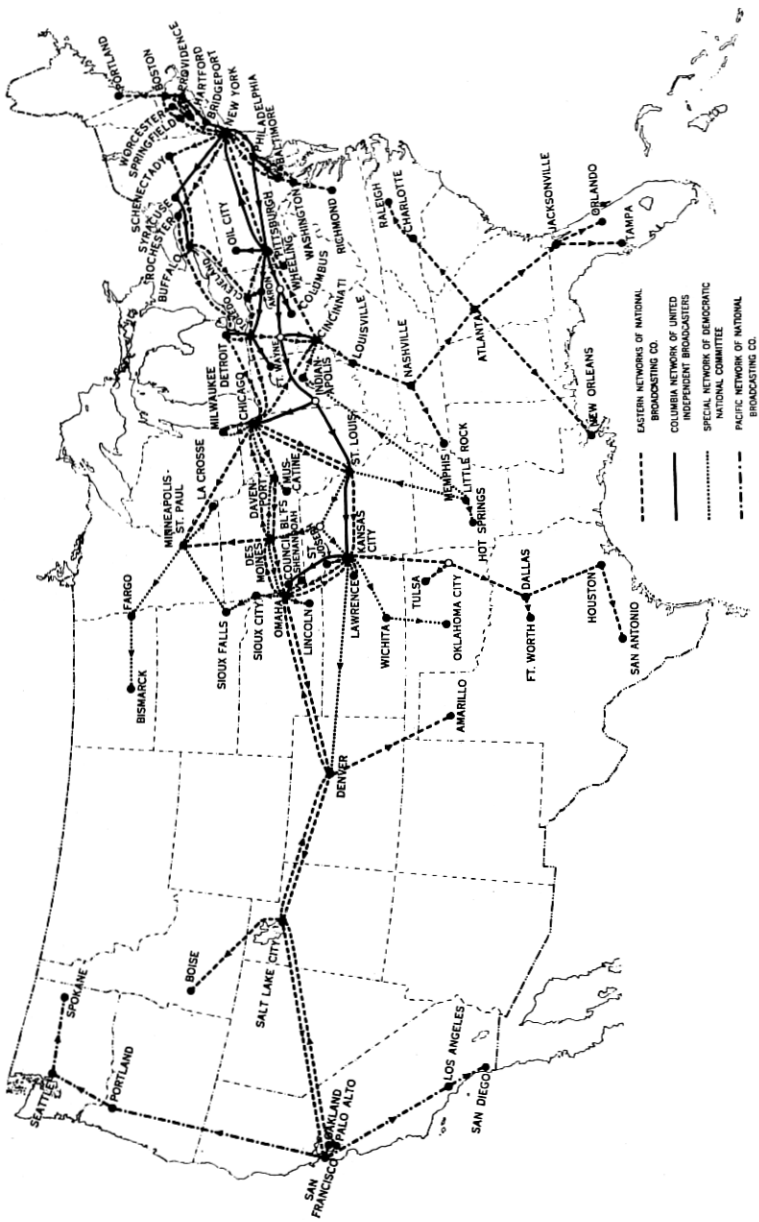

Fig. 2—Bell System Program Networks Operating on Last Night before 1928 Presidential Election.

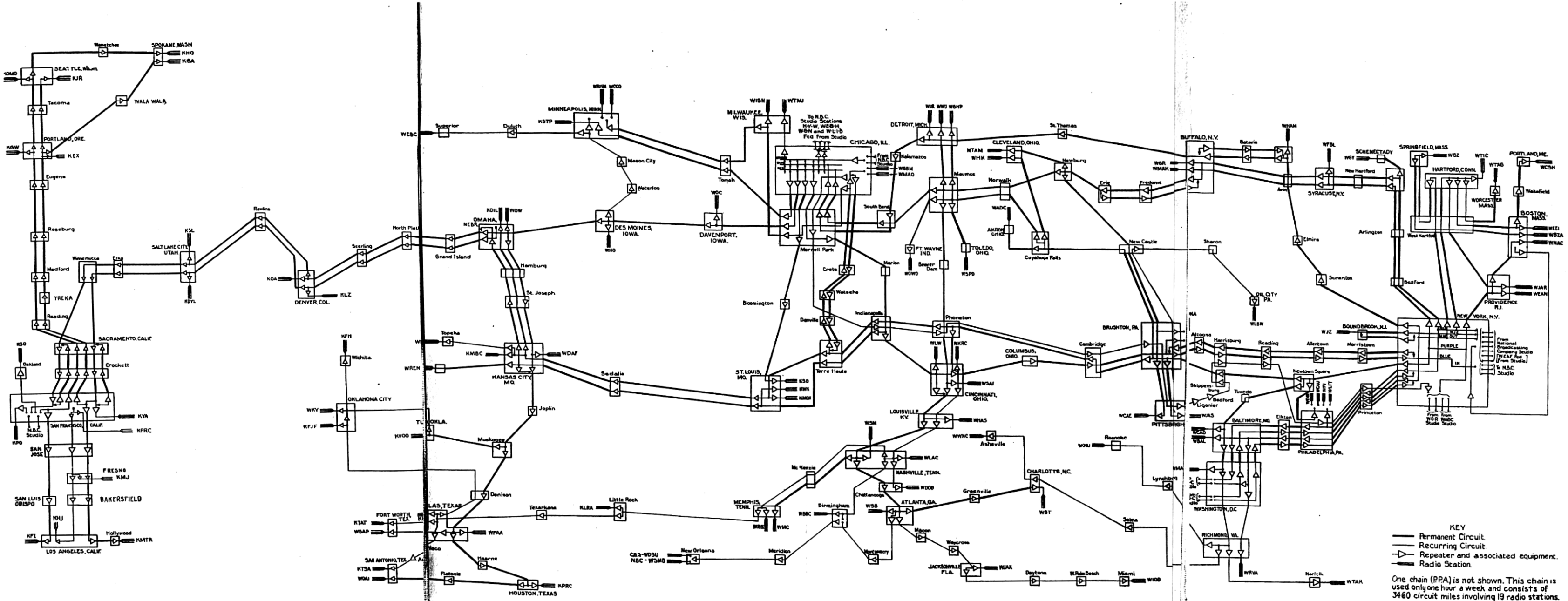

Fig. 4—Layout of Permanent and Recurring Program Network Circuits with Associated Repeater Equipment Shown on the Basis of Normal Direction of Transmission as of January 15, 1929.

the various chains are interconnected and arranged for switching at certain distributing centers.

In the United States the largest distributing center is, naturally, in New York City, since the bulk of the program material originates at that point. At such a distributing center a special collection of various forms of equipment is provided consisting of one-way amplifiers, loud speakers, multifrequency oscillators, various forms of transmission measuring devices and miscellaneous apparatus. The photograph of Fig. 5 shows a portion of the program layout in the New

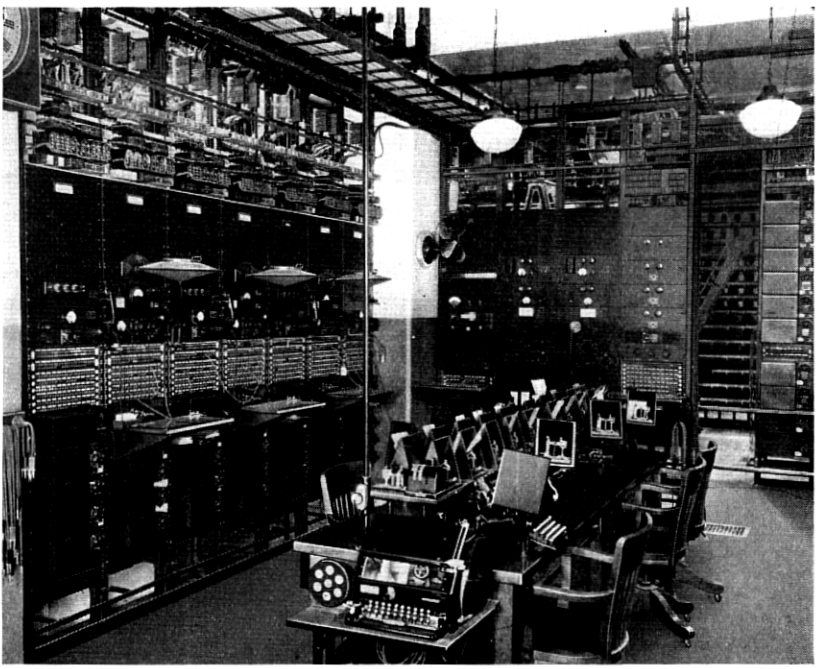

Fig. 5—Portion of Program Apparatus Layout in New York Long Distance Telephone Office as of January 15, 1929.

York long distance telephone office as of January 15, 1929. The various bays at the left carry the line apparatus associated with branches of various chains. In the rear are located the transmission measuring apparatus and multifrequency oscillators. In the foreground are the terminals of various telegraph order wires.

In transmitting programs over a wire network, as has been pointed out above, it is important that the volume range be held within

proper limits. It is one of the obligations of the one who "picks up" the program to hold his range of volume between proper limits. At the central distributing point those in charge of the wire circuits usually find it desirable to make checks from time to time to insure that the proper range of volume is maintained. This checkup is made by means of a device known as a "volume indicator" similar to the one which the program supplier uses for purposes of regulating his volume range. Other volume indicators are provided at various strategic points in the wire network in order to insure that the proper range of volume is reaching these points. In addition to regularly making these observations by means of volume indicators, loudspeaker monitoring observations are continually made at practically all repeater points.

The results of these observations are transmitted back to the control points periodically by means of telegraph order wires so that the control operator knows at all times the condition of transmission at every point in his territory.

With the network chains grown to such vast proportions as indicated in Figs. 1 and 4, it is essential that the system for controlling the networks be such that all points involved be in instant communication with certain designated control points. To accomplish this, the United States has been divided into four areas, each area of which is under the control of a distributing center or control station. The four control stations in the United States at present (January 15, 1929) are, New York covering the eastern section, Chicago the western section, Cincinnati the southern section, and San Francisco the Pacific Coast section. Each of these control points is connected to every repeater point in its area by means of telegraph order wires and in addition is connected to every radio station in the area served by the networks under its control. The various control points are also connected together by means of order wires and arrangements are provided so that New York can be placed in communication with any of the radio stations in the United States which are served by the chains. The total telegraph wire mileage employed for this service is now approximately 43,000 miles (70,000 kilometers).

A large corps of specially trained telephone men is needed to properly supervise the transmission performance of the chains as well as to take care of the switching and general coordination work involved. At present, about 300 men are employed in the United States for this service, these men, of course, being in addition to those who care for the regular wire and equipment maintenance.

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