How Chain Broadcasting Is Accomplished

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CHAIN broadcasting is known to radio listeners as a means whereby a radio program may be transmitted by several or even dozens of radio stations. Regular networks furnish entertainment every day, and on important occasions great extensions are made so that practically the entire United States is covered. The estimated audiences at such times include one fourth to one third of the entire population of the country. More people have thus listened to the voice of one person than ever before in history.

The apparatus and methods whereby such important and remarkable results are accomplished are, therefore, interesting subjects to the radio fan. His knowledge of vacuum tubes, audio-frequency amplifiers, and electrical principles will enable him to appreciate various interesting points in the equipment and operation of the wire lines used in chain broadcasting.

In addition to the long lines connecting to radio stations in distant cities, there are many shorter lines transmitting programs, such as from studios centrally located in large cities to the powerful radio broadcasting apparatus out beyond the suburbs. Similar circuits are used to broadcast sporting events, banquets, and other occurrences outside the studio, thus greatly extending the range of program features.

It is one of the duties of telephone engineers and operating men to plan and supervise both the short and long lines which carry radio programs. These connections differ in various respects from regular local and long distance telephone lines, and have, therefore, been given a special name, "program circuits." One difference is that ordinary telephone circuits transmit the voice in both directions (on long circuits "two-way" amplifiers are therefore necessary), but in program circuits it is necessary to transmit only in one direction, that is, from the pick-up microphone to the one or more radio transmitting stations. "One-way" repeaters are therefore sufficient. In the drawing on page 66 arrows indicate the direction of transmission along each program circuit which was used on January 4th, 1928, the date of the first Dodge Brothers program. The regular route of the voice of Will Rogers, acting as master of ceremonies at Los Angeles, may be followed by way of San Francisco and Denver to Chicago and the East. Also an additional circuit for use in case of emergency is seen passing through southern New Mexico, Dallas, and St. Louis to Chicago.

THE CHAIN BROADCASTING CONTROL ROOM IN CHICAGO

Similar control rooms are located in Boston, Cincinnati, Detroit, St. Louis, Atlanta, San Francisco, and New York, each in charge of a "transmission supervisor." Repeaters, oscillators, equalizers, transmission measuring devices, and other apparatus necessary in the exacting work of transmitting the programs are shown in the illustration. Cone loud speakers are mounted in the protecting frames at the left. During operation, one cone is connected to the Red network, another to the Blue, a third to the Purple; the fourth is a spare.

MEETING THE TRANSMISSION REQUIREMENTS

ANOTHER important difference between ordinary telephone circuits and program circuits is in the width of the frequency band transmitted. In a telephone conversation, clear, intelligible speech is desired, and it has been found that this can be obtained if frequencies from about 300 cycles per second to about 2000 cycles per second are transmitted, although modern telephone circuits are engineered to carry a somewhat wider frequency range. However, with program circuits, not only satisfactory intelligibility is desired, but also a very high degree of naturalness and faithfulness in the transmission of music and speech when reproduced through loud speakers. To meet these requirements, a much wider band of frequencies is necessary. In the present art it is generally considered desirable to transmit a range of frequencies from about 100 cycles per second to about 5000 cycles per second, and to do this with approximately uniform efficiency. In this way the low, medium and high pitch ranges of music and other program material are transmitted with a considerable degree of faithfulness.

In addition to the wider frequency-range requirements, program circuits are called upon to transmit greater volume variations than ordinary telephone circuits. For example, the music of a symphony orchestra will vary from a very loud intensity, when many instruments are sounding, to a very faint intensity at other times.

What Radio Owes to Chain Broadcasting

THE Washington air, in and near the halls of Congress, has been full of pointed and often unpleasant comments about chain broadcasting during the recent weeks when the last radio bill was under consideration. Aside from the political aspects which so fascinate our legislators, it can be said without fear or favor that chain broadcasting is responsible almost entirely for the growth of high-grade programs in this country. Chain broadcasting has partially solved the old question: "Who is to pay for broadcasting?" As the use of the wire network, linking stations, has increased, so has the radio audience, and with it the time, money, and effort expended on programs. This article explains some of the technical aspects of the accomplishment, much of which appears for the first time.

—THE EDITOR.

At all times extraneous noise on the circuit must be slight in comparison with the volume of the music. The critical times are during the faint portions of the program, and to transmit these satisfactorily, a very quiet circuit is obviously necessary.

The large variations in the volume of orchestral music (which are of the order of 50 TU, an energy ratio of 100,000) are greater than radio stations can transmit without overloading on the loud signals and losing the faint portions in local noise, static, etc., at the receiver. So at the microphone amplifier one of the broadcast station control operators manipulates the amplification control so as to reduce these variations, cutting down somewhat the loud portions and bringing up somewhat the faint portions, taking care to preserve as nearly as possible the naturalness of the music. The program circuits, i. e., wire lines are quiet enough to be able to more than handle all the volume variation which the broadcasting radio stations desire to transmit.

Besides the requirements just considered, the program circuits must of course function harmoniously with the other circuits of the telephone plant, so that program transmission will not be overheard on the ordinary circuits, nor vice versa.

For short connections in cities and at other places, circuits in cable are usually employed. The attenuation, the loss, introduced by a seven-mile length of 19-gauge cable pair (consisting of No. 19 B & S copper wire), with no loading coils or other apparatus connected, increases considerably with increase of frequency. One TU of loss means a reduction of power to 79½ per cent. of its original value, two transmission units means a further reduction to 79½ per cent. of what is left, or to .795 x .795 = .63 = 63 per cent. of the original amount.

Three TU is a power ratio of 50 per cent., four is 40 per cent., and five TU 32 per cent. Twenty TU is a power reduction to 0.01 or 1 per cent. of its original value, as shown by the bottom line of the chart. (TU are also used to express the amount of amplification, or "gain," of an amplifier, the ratio being the reciprocal of that for loss. Thus, 20 TU gain is $\frac{1}{.01} = 100$ times, meaning that the output power is 100 times as great as the input power. For further information on TU see Martin, *Journal, A. I. E. E.* June, 1924).

If the cable mentioned were used without any correcting agency there would be a serious reduction in the strength of the high-pitch components which give music its charm and brilliancy. But frequency distortion, if not too great, can be offset by introducing an opposite distortion, a veritable case of two bad elements combined to achieve the desired good result.

To correct the frequency characteristic of short cable, special devices called "equalizers" are used. These consist of inductance, capacitance, and resistance, three of the elements forming a parallel resonant circuit, such as is familiar to radio amateurs from its use as a wave-trap. However, here the elements are so chosen that the resonant frequency is far lower, lying a little above the range of frequencies which the circuit transmits. As in a wave-trap, the impedance is high at the resonant frequency, so that here the equalizer introduces little loss since it is shunted across the line. But at lower frequencies the impedance is much less, and by proper adjustment of the two resistances and the equalizer is made to have characteristics just the opposite of those of the cable pair. The resulting curve for the cable with the equalizer is practically horizontal, which is the result desired. The volume is then raised to a higher level by a distortionless amplifier.

For the long connections between cities in chain broadcasting, "open wire" circuits are largely used, that is, circuits consisting of wire on insulators supported by cross arms. Most of this wire is hard-drawn copper (No. 6 B. & S.) 0.165 inches in diameter, the most rugged type of open wire line used in the Bell System. The energy loss along this type of line is much less than along an equal length of the cable just considered, but after the current has traveled about two or three hundred miles it must be reinforced. For this purpose an audio-frequency amplifier, called a "repeater," is used.

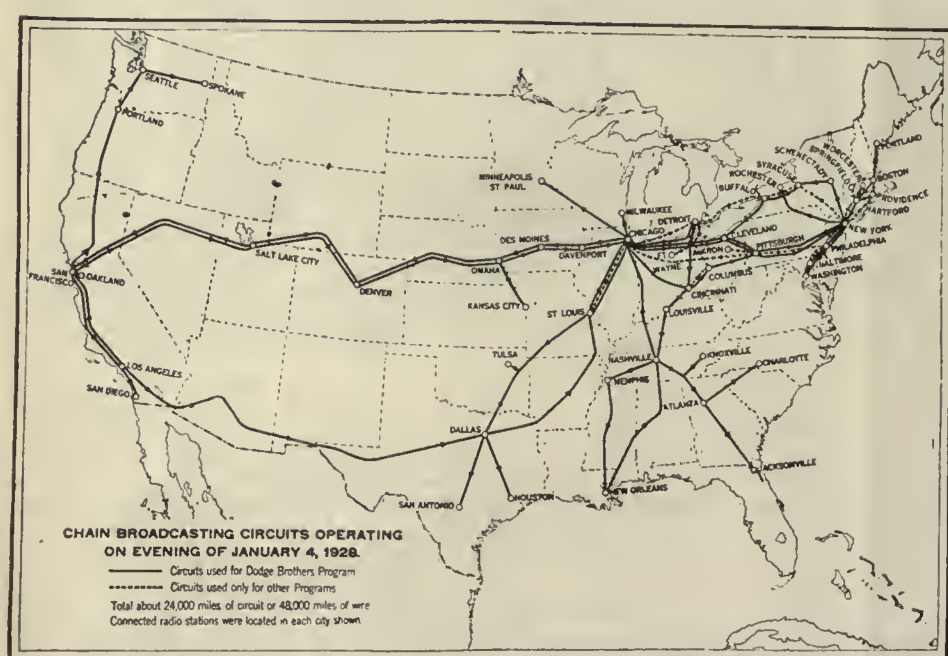
An open wire circuit is similar to cable in that the energy loss is greater at high frequencies, but somewhat different methods are used to make the open-wire frequency characteristic horizontal. Repeaters which introduce greater amplification for the high frequencies are used in conjunction with equalizers. These equalizers are different from the cable equalizer since the conditions are not the same.

TELEGRAPH AND AMPLIFIER ARRANGEMENTS

PARALLELING every long program circuit is a telegraph circuit over which reports and instructions are transmitted. With keys and sounders at every repeater station this provides an auxiliary communication channel for the use of those responsible for the program circuit. Other telegraph circuits connect the radio stations on each chain with the key station for the coördination of station announcements and other program details.

One of the most interesting features of a program network is the means employed to restrict the effect of an accidental short-circuit of the line at any point. Without the methods used, such a short-circuit, besides preventing any transmission beyond the particular point, would greatly reduce the voltage for a considerable distance back along the line. Now an amplifier, besides its primary purpose, has the important property that a change in the condition of the output circuit (such as a short), has practically no effect on the input circuit. So, wherever a program circuit forks, an amplifier is inserted into each outgoing branch, with the result that a short-circuit across one branch will not affect the transmission along the other branch. This is done regardless of whether or not amplification is needed—the one-way feature of an amplifier is taken advantage of in this way to increase the reliability of the system. For this reason repeaters average about 125 miles spacing in the East, when otherwise two or three hundred miles would be sufficiently close, for there are numerous forking points in this part of the country.

The drawing on page 67 illustrates, by a typical case, the manner in which the power decreases along each section of a program circuit and is built up to its original value at the repeater points. For example, at the New York repeater station the incoming power from the radio studio is given a net amplification of 9 TU, and then begins the trip to Troy, New York.



CHAIN BROADCASTING CIRCUITS OPERATING ON EVENING OF JANUARY 4, 1928.
——— Circuits used for Dodge Brothers Program
- - - - Circuits used only for other Programs
Total about 24,000 miles of circuit or 48,000 miles of wire
Connected radio stations were located in each city shown

Along the circuit the power decreases steadily until at Troy it is only 3 TU above the original input at New York. Here it is amplified again, and continues on toward Syracuse. The maintenance of a horizontal frequency characteristic, the importance of which has already been stated, necessitates the introduction of losses at the repeater points which are offset by amplification; for simplicity these are not indicated, the net gain at each repeater station being shown. The final output power of the circuit at Chicago is seen to be four times greater than the input power at New York. The scale at the right gives for any point the number of TU by which the power at that point exceeds the input to the circuit at New York. The left scale gives the corresponding power ratio.

THE AMPLIFIERS OR "REPEATERS"

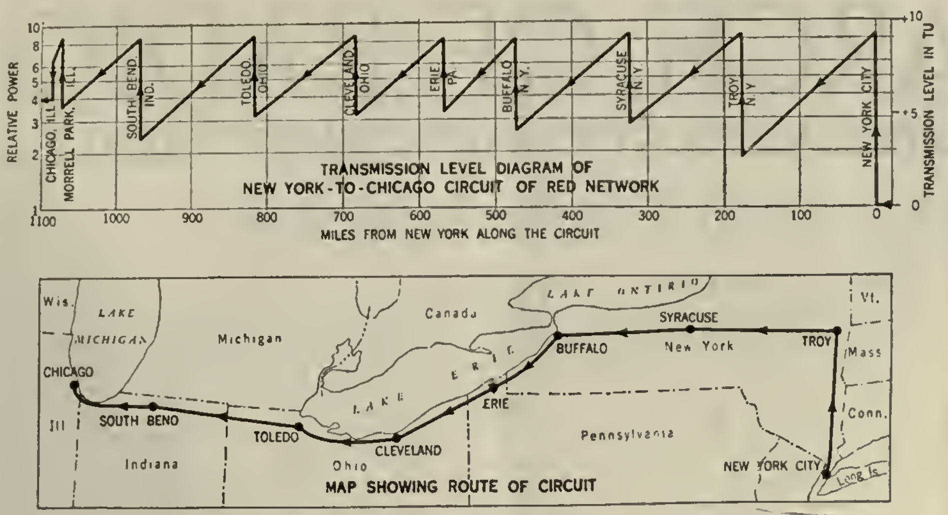
OF COURSE, the transmission of music and speech over program circuits is by alternating currents having frequencies the same as those which are present acoustically in the sound at the microphone. So the repeaters in the circuit are audio-frequency amplifiers. At the end of each program circuit in chain broadcasting is a radio transmitting station which sends the program out on the ether at a radio frequency.

Special study has been devoted to the design of telephone repeaters, and various types have been developed. Those used in program circuits are two-stage, transformer-coupled amplifiers using 130 volts plate supply. The first main element of the repeater is an input transformer whose secondary is tapped to allow adjustment of the amplification given by the repeater. The tapped voltage from this transformer is applied to a high-mu tube having an amplification factor of about 30, and an output resistance of about 60,000 ohms. From this tube the energy goes through an inter-stage transformer to the second stage. Here there is a tube having an amplification factor of about 6 and an output resistance of about 6000 ohms, similar to the 216-A or 112 type tubes which have been used in other amplifiers. There is an output transformer for delivering the amplified energy to the outgoing program circuit. Provisions are made for close adjustment of amplification and for adjustment of the frequency characteristic. The amount of amplification or "gain" in the repeater may be adjusted to any value over a range of 37 TU in steps of as little as 0.3 TU so that very accurate setting is possible. At 1000 cycles this adjustment varies the gain from 5 TU to 42 TU, which is the same as varying the power amplification from 3.2 to 15,800, or the voltage amplification from 1.8 to 126.

TESTING AND OPERATION OF PROGRAM CIRCUITS

A FEW years ago the testing and operation of all the program circuits then in use was in charge of one "transmission supervisor" located in New York. Since then, the extent of program circuits has grown by such bounds that it has become necessary to have additional transmission supervisors, and these are now located at Boston, Cincinnati, Detroit, Chicago, St. Louis, Atlanta and San Francisco. Each transmission supervisor is responsible for the program circuits going out from his control point. He, therefore, has charge of hundreds of miles of circuits and a number of repeater stations, through which the circuits pass. At each of the repeater stations there are trained men who are on duty during the hours that the program circuits are being tested or used, and these men make reports to the transmission supervisor, as directed, and adjust their apparatus in accordance with his instructions.

It is very important to maintain the program circuits in the best of condition, for many thou-



WHAT HAPPENS TO ENERGY IN WIRE CIRCUITS

How the voice-frequency currents are attenuated as they travel over long lengths of wire. Note the effect of amplification at the repeater points

sands of radio listeners are dependent upon them. Each transmission supervisor, therefore, conducts every morning a thorough test and adjustment of all the circuits under his charge. Transmitting a tone of 1000 cycles over the program circuits, he receives reports by telegraph and directs adjustments at the nearest repeater station, then at the next repeater station, etc., until, in this way, the entire group of circuits under his charge is "lined up." Then a low frequency, about 100 cycles per second, is transmitted and any necessary auxiliary adjustments are made to see that this low pitch is transmitted with the same efficiency as the 1000 cycles. Then a high frequency of about 5000 cycles is transmitted to check the characteristics at this end of the frequency range, and if necessary, appropriate adjustments are made. Finally, music from a phonograph is sent over the circuits to give a working check on their condition.

The transmission supervisor is also responsible for the operation of the program circuits during use. As soon as a report of transmission difficulty reaches him, he must take immediate steps to correct it. Whether the trouble is noise on the circuit or low volume, he must proceed immediately with the proper steps. Sometimes the volume delivered by a circuit will diminish or the circuit will become noisy so as to suggest approaching failure. In this case he endeavors to obtain an alternative circuit and substitute it; sometimes this may be done before the radio listeners realize that any trouble has occurred. At other times a circuit may, without warning, fail completely, and at such times the transmission supervisor's general knowledge of the situation is put to the test. He may sometimes succeed in obtaining an alternative circuit with only three or four minutes interruption to the program. Sometimes alternative circuits follow different routes and far exceed in length the facilities they replace, such as during the Democratic Convention in 1924 when a connection 1400 miles long was substituted in place of one only 200 miles long. The transmission supervisors even keep informed of the weather conditions over a large part of the country so that, in case of threatening storms, they may obtain emergency routes and hold them in readiness.

The heading shows the program circuit control point at Chicago. Repeaters, equalizers, oscillators, transmission measuring devices, and other apparatus, may be seen mounted at the left and in the rear. One cone is connected to the Red Network program, another to the Blue Network, another to the Purple Network (the Columbia Chain), and the fourth is a spare. In this way, constant check is kept on the quality of the program transmission. At the right are telegraph operators who transmit messages between the transmission supervisor and the different repeater stations under his direction.

NETWORKS REGULARLY OPERATING

THERE are now four networks in daily operation, namely, the Red, Blue and Purple networks in the East, and the Pacific Coast network in the West. The eastern networks are supplied with studio programs from New York City and the Pacific Coast network from San Francisco. The total length of program circuits permanently connected into these four networks, or connected on a regular recurring basis, was, on April 1, more than 15,000 miles. To maintain and operate this great amount of program facilities required more than 25,000 miles of telegraph circuit. The daily audiences listening to the programs from these chains are estimated in the millions of persons.

Perhaps the reader has wondered how the designation of networks by colors originated. This occurred several years ago when the only network then operating received programs from WEAF in New York. The telephone engineers drew in red pencil, on a map, the circuits regularly connected and drew in blue the extensions which were occasionally added. In this way the regularly operating chain became known as the "Red network." Later, when a network was organized with WJZ in New York as the key station, the name "Blue network" was, of course, given to this. At the important program control points the designation of the networks by colors is a considerable aid to the transmission supervisor in the necessary switching operations.

HISTORICAL SPECIAL HOOK-UPS

ON DEFENSE Day, September 12, 1924, two-way conversation between General Pershing in Washington and the Commanding Generals of the various Corps Areas in New York, Chicago, San Francisco and other points was transmitted to a number of radio stations and heard by many thousands of listeners. This occasion remains an unbroken record for the broadcasting of two-way conversation.

The largest number of radio stations ever connected was during the Radio Industries Banquet held in New York on September 21, 1927, when a total of 85 radio stations broadcast the proceedings. All four of the regular networks were used and 13 additional points were added.

Doubtless many readers will recall the first Dodge Brothers broadcast of January 4, 1928, when well-known persons in Los Angeles, New Orleans, New York, Chicago and Detroit were heard. The circuits used in this broadcast are shown in heavy lines in the drawing on this page, totaling over 20,000 miles of circuit, or over 40,000 miles of wire. Other program circuits operating on this date but not transmitting the Dodge program bring the total program mileage to about 24,000 miles of circuit or about 48,000 miles of telephone wire. In addition to this telephone mileage, about 40,000 miles of telegraph circuit was employed for lining-up and operating the program circuits. As the pick-up point was changed from one city to another, the circuits had to be switched at correspondingly widely separated switching-points. To perform these operations in the necessary order within the allotted five seconds required thorough training and a high degree of intelligence. All the pick-up circuits not in use for a few minutes were kept under continuous test to guard against the development of line troubles during these intervals.