Wide-Band Open-Wire Program System *

By H. S. HAMILTON

Radio programs are regularly transmitted between broadcasting stations over wire line facilities furnished by the Bell System. Both cable and open wire facilities are employed for this service. Recently a new program transmission system for use on open wire lines has been developed which has highly satisfactory characteristics. A description of this open wire system and test results obtained with it are given in this paper.

THE simultaneous broadcasting of the same radio program from a large number of broadcasting stations, in different sections of the United States, has become of such everyday occurrence that the radio listening public takes it as an accepted fact and in many cases does not know whether the program is originating in the studio of a local broadcasting station or in a broadcasting studio in some distant city. The wire line facilities furnished by the Bell System for the interconnection of the radio stations, particularly the wire line facilities in cable, have such transmission characteristics that little detectable quality impairment is introduced even when programs are transmitted over very long distances.

This cable program system was described in a recent paper.[1] More recently a new program system for use on open-wire lines, which possesses transmission characteristics comparable with those of the cable system, was developed and an extensive field trial made involving two circuits between Chicago and San Francisco. This paper describes this new open-wire program system and gives the principal results of the tests made on the two transcontinental circuits.

In the paper referred to describing the cable system, the various factors and considerations involved dictating the grade of transmission performance that is desired for program circuits were discussed in considerable detail so they will not be reviewed here. The transmission requirements chosen as objectives for both cable and open wire are as follows:

Frequency Range

Frequency range to be transmitted without material distortion—about 50 to 8,000 cycles.

* Published in April, 1934 issue of *Electrical Engineering*. Scheduled for presentation at Pacific Coast Convention of A. I. E. E., Salt Lake City, Utah, September, 1934.

[1] A. B. Clark and C. W. Green, "Long Distance Cable Circuit for Program Transmission," presented at A. I. E. E. Convention, Toronto, June, 1930; published in *Bell Sys. Tech. Jour.*, July, 1930.

Volume Range

Volume range to be transmitted without distortion or material interference from extraneous line noise—about 40 db which corresponds to an energy range of 10,000 to 1.

Non-Linear and Phase Distortion

Non-linear distortion with different current strengths and phase distortion to be kept at such low values as to have negligible effect on quality of transmission even on the very long circuits.

The frequency range afforded by the new open-wire program circuits extends about 3,000 cycles higher and more than 50 cycles lower than the frequency range available with the open-wire [2] program circuits previously used. The extension of the frequency range at the upper end necessitates the sacrifice of one carrier telephone channel of carrier systems operating on the same wires with the program pair since the frequency band of the lowest carrier channel lies in this range. In order to minimize noise and the possibility of crosstalk, the phantoms of program pairs are not utilized and, of course, d.-c. telegraph compositing equipment is removed in order that the proper low-frequency characteristics may be realized.

Description of New Open-Wire System

In general, the amplifiers on the open-wire program circuits employ the same spacing as the telephone message circuit repeaters on the same pole lead. The average repeater spacing is about 150 miles but the repeaters may be located as close as 60 miles or may be as much as 300 miles apart depending on the location of towns and cities on the open-wire route and the gauge of the wires used. The upper diagram of Fig. 1 shows a typical layout of the new wide-band open-wire program system. Three types of stations are shown, a terminal transmitting station, an intermediate station which may be either bridging or non-bridging and a terminal receiving station.

The terminal transmitting station includes an equalizer for correcting for the attenuation distortion of the local loop from the broadcasting studio, an attenuator for adjusting the transmission level received from the local loop to the proper value, an amplifier for inserting the required gain, filters for separating the program and carrier channels, monitoring amplifier, loudspeaker and volume indicator for

[2] A. B. Clark, "Wire Line Systems for National Broadcasting," presented before the World Engineering Congress at Tokio, Japan, October, 1929; published in *Proc. I. R. E.*, November, 1929, and in *Bell Sys. Tech. Jour.*, January, 1930. F. A. Cowan, "Telephone Circuits for Program Transmission," presented at Regional Meeting of A. I. E. E., Dallas, Texas, May, 1929; published in *Transactions of A. I. E. E.*, Vol. 48, No. 3, pages 1045–1049, July, 1929.

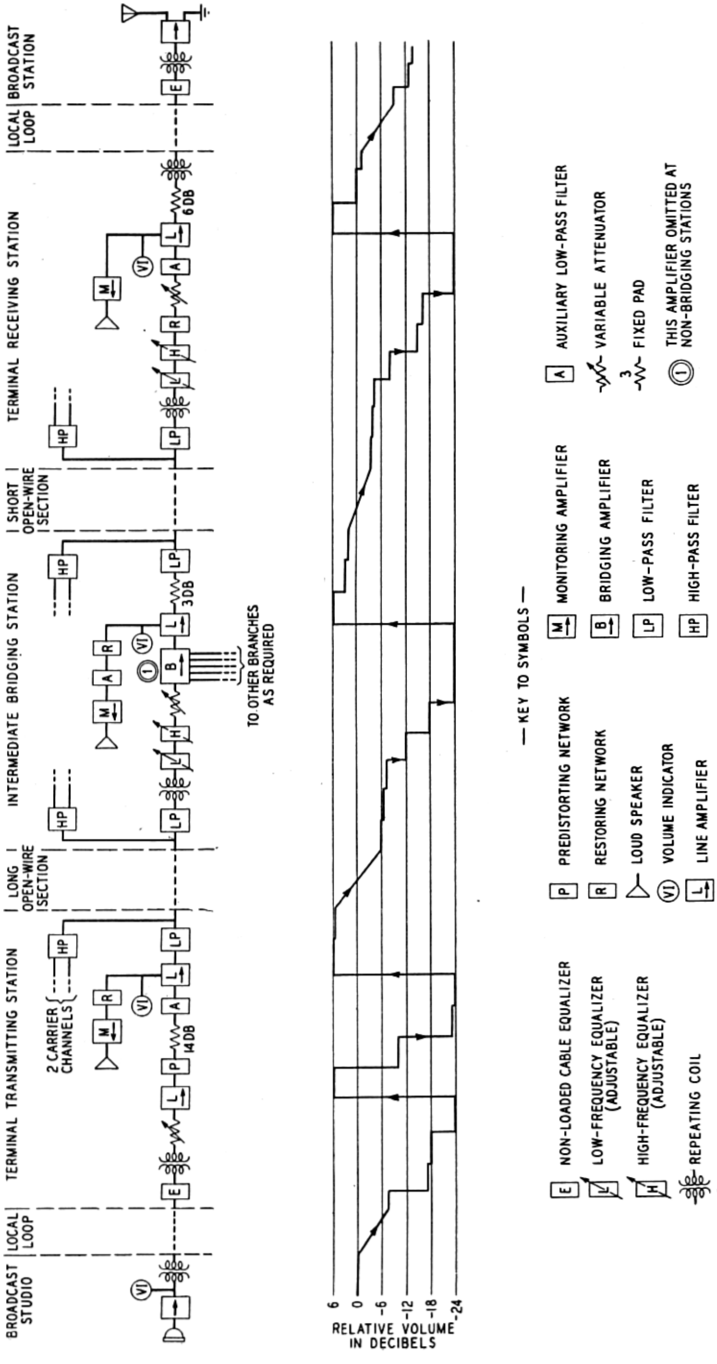

Fig. 1—Typical circuit layout and level diagram.

making the necessary operating observations and a predistorting network and associated amplifier.

At the intermediate station are included line filters for separating the carrier currents and program currents and directing them to their proper channels, two adjustable attenuation equalizers for correcting for the attenuation distortion of the line wires and associated apparatus, gain control attenuator, line amplifier and associated monitoring equipment. At intermediate stations where it is necessary to provide branches to radio stations or to other program circuits an amplifier of a special type having several outlets is inserted immediately in front of the line amplifier.

At a receiving terminal, the layout employed is very similar to that utilized at intermediate stations except that an additional low-pass filter and a restoring network are inserted ahead of the receiving amplifier.

A novel feature is provided in this program system for minimizing its susceptibility to interference at higher frequencies. It consists in predistorting the transmission at the sending end of the circuit so that currents above 1,000 cycles are sent over the line at a higher level than if this arrangement were not employed, thus increasing the signal-to-noise ratio at these frequencies. Such an increase in power at high frequencies is permissible without overloading in the line amplifiers in view of the fact that the energy content of the program material above 1,000 cycles is materially less than at the low frequencies and decreases rapidly as the frequency is increased. In order to restore the program material to the same relations it would have if it were not predistorted, a network is inserted at each point in the branches which feed the radio stations and at the receiving terminal. This network introduces attenuation and phase distortion which are complementary to those introduced at the sending end of the circuit by the predistorting network. The net reduction in high-frequency interference is equal to the discrimination introduced by the predistorting network in favor of these frequencies, and is therefore equal approximately to the loss of the restoring network at the same frequencies.

In the lower part of Fig. 1 is shown a level diagram, from which may be noted the losses and gains introduced by different parts of the system at a frequency of 1,000 cycles. The maximum volumes which are permitted in the various parts of the system are also indicated approximately by this diagram.

Line Facilities

As is well known the open-wire lines employed in telephone and program service do not have uniform attenuation for all frequencies, the low frequencies being transmitted with much less loss than the high frequencies. Since the program circuits employ the same type of open-wire facilities that is used in the message circuits, three different gauges of wire with either of two pin spacings between wires may be used and the repeater sections may vary in length from 60 to 300 miles. This means that the attenuation frequency characteristic of a repeater section not only varies with frequency but also varies considerably in magnitude of attenuation depending on gauge of wire and length of repeater section.

On Fig. 2 are shown three pairs of characteristics which illustrate the loss-frequency characteristics of three lengths of 165-mil, 8-inch

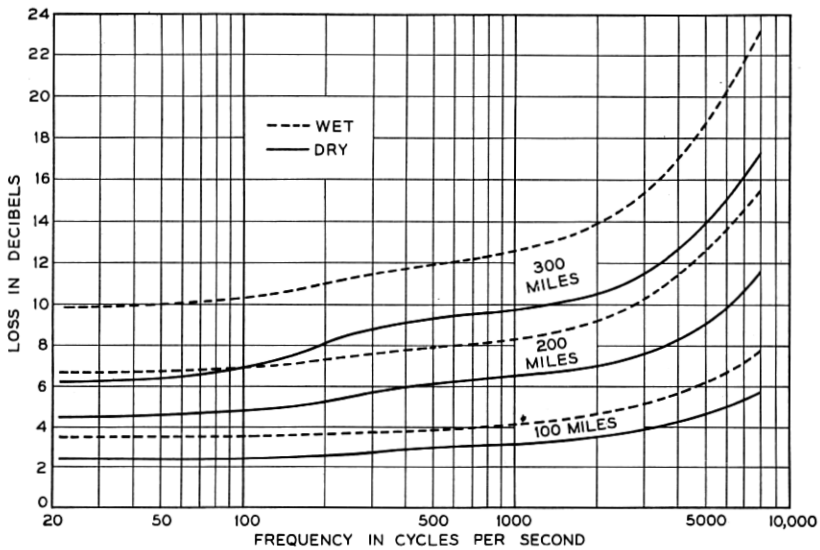

Fig. 2—Loss of 165-mil. 8-inch spaced pairs when inserted between 600-ohm resistances.

spaced circuits. The lengths chosen for purposes of illustration are 100, 200 and 300 miles, respectively. The solid line curves show the insertion loss-frequency characteristics of the circuits for average dry weather conditions when the circuits are connected between 600-ohm resistances. The dashed line curves indicate the wet weather insertion loss characteristics, that is, they indicate the loss-frequency characteristic which might obtain if the lines were very wet for the entire length of a repeater section.

For the purpose of comparing the attenuation frequency characteristics of the different types of open-wire lines, the curves shown on Fig. 3 have been prepared. These characteristics have been plotted so

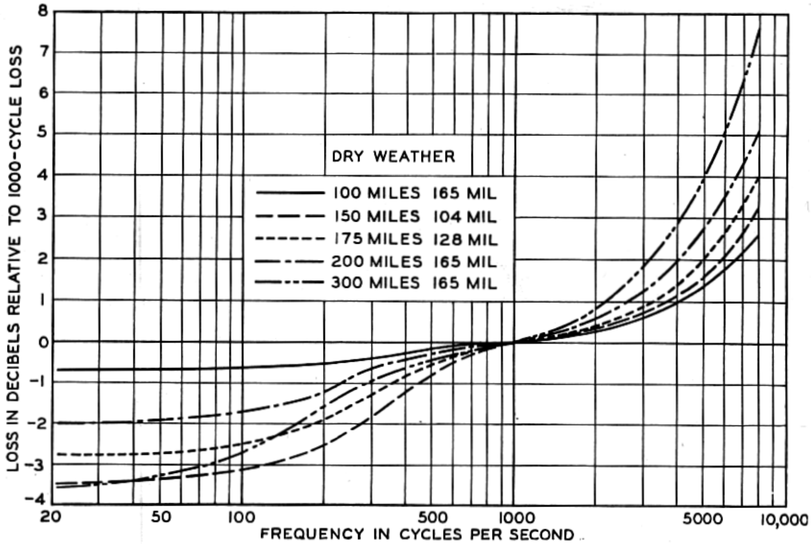

Fig. 3—Attenuation characteristics of 8-inch spaced open-wire pairs when inserted between 600-ohm resistances.

that all coincide at 1,000 cycles; thus a direct comparison of the difference in shape of the attenuation frequency characteristics may readily be observed.

Figure 4 shows resistance and reactance components of 165-mil and 128-mil 8-inch spaced open-wire lines. Note that, except at low frequencies, the impedances of the various open-wire lines are quite uniform throughout the frequency range and do not depart greatly from 600 ohms. For this reason and in consideration that the majority of telephone apparatus is designed for 600-ohm impedance, all units of this new program system, except the carrier line filters, have been designed to have an impedance of 600 ohms. In order to reduce reflection losses, particularly in the carrier range, the line filters have been designed to have an impedance on the line side somewhat lower than 600 ohms although the drop or office side impedance is 600 ohms.

Attenuation Equalizers

To furnish the necessary attenuation corrections for the three different gauges of lines, four adjustable attenuation correcting networks have been provided. One attenuation equalizer provides attenuation correction for high frequencies only and is common for all gauges. The three other equalizers provide low-frequency attenuation correction designed specifically for the particular gauge of circuit the

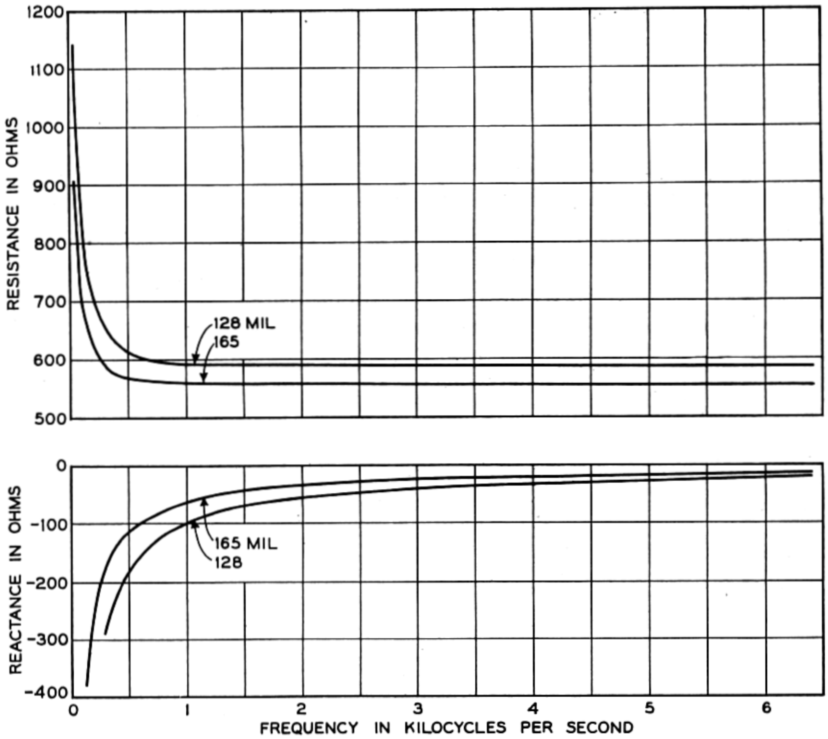

Fig. 4—Impedance of 8-inch spaced open-wire pairs.

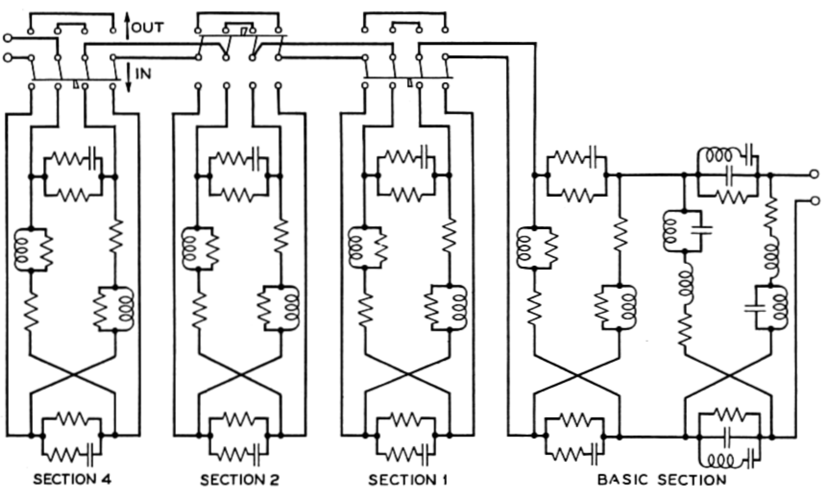

Fig. 5—Low-frequency attenuation equalizer.

equalizer is to be associated with and also include a fixed amount of high-frequency attenuation correction.

On Fig. 5 is shown a schematic diagram of one of the low-frequency attenuation equalizers. This consists of four sections of 600-ohm constant impedance type networks. One section referred to as a basic section introduces attenuation correction over the complete frequency range from 35 to 8,000 cycles for a particular minimum length of line, as for example, in the case of 165-mil circuits this is for 100 miles. The three other sections on the other hand furnish attenuation correction only for frequencies from approximately 1,000 cycles down to 35 cycles. Section 1 of the equalizer for 165-mil circuits puts in about ½ db more loss at low frequencies than it does at 1,000 cycles. Section 2 puts in double the amount of correction that is introduced by Section 1 and Section 4 introduces four times as much attenuation correction as Section 1. These three sections are controlled by switches so that any one or all of them may be cut in tandem with the basic section. The attenuation corrections afforded for the various adjustments of this equalizer are shown on Fig. 6.

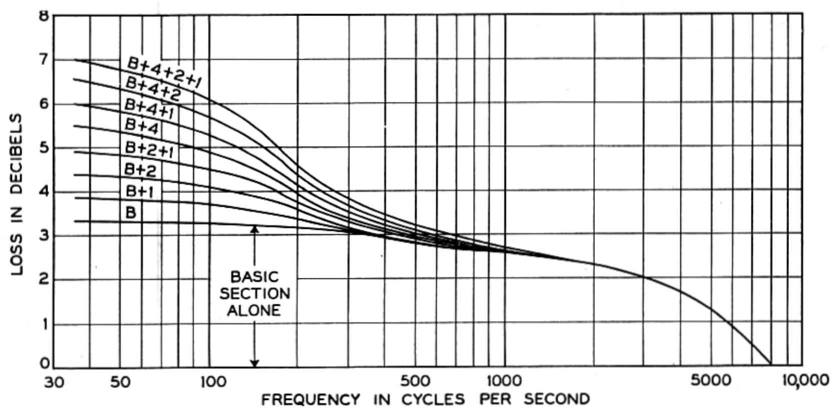

Fig. 6—Attenuation correction furnished by low-frequency equalizer for 165-mil. circuits.

The attenuation equalizers for 128-mil and 104-mil facilities are similar in construction to the one just described having different constants so as to furnish somewhat different attenuation correcting characteristics.

Figure 7 shows a schematic diagram of the high-frequency attenuation equalizer. This consists of four 600-ohm constant impedance type network sections which, as indicated, are controlled by switches so that any one or all of them may be cut in tandem with the program

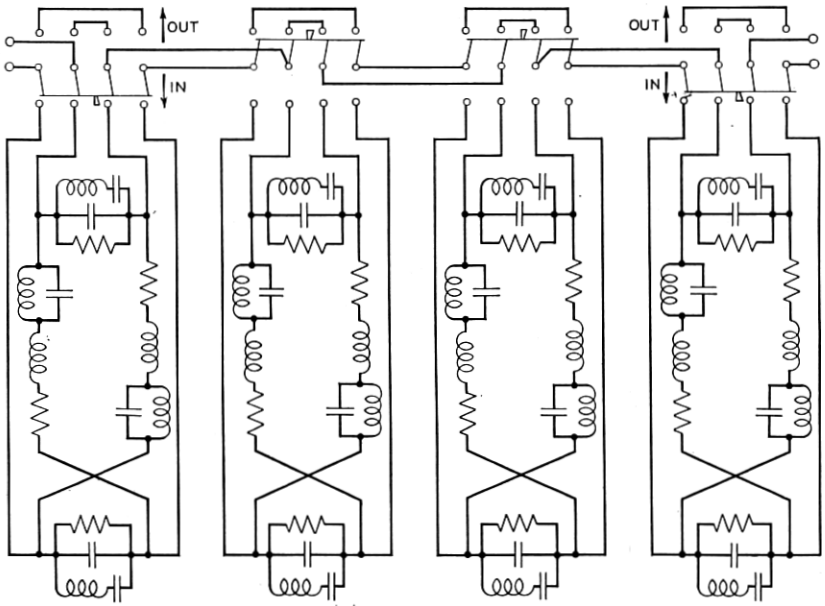

Fig. 7—High-frequency attenuation equalizer.

circuit as required. Figure 8 shows the loss-frequency characteristics of these four sections. As may be noted, the loss of the various sections is practically constant over the frequency range up to 1,000 cycles, decreasing from there on to a minimum value at 8,000 cycles.

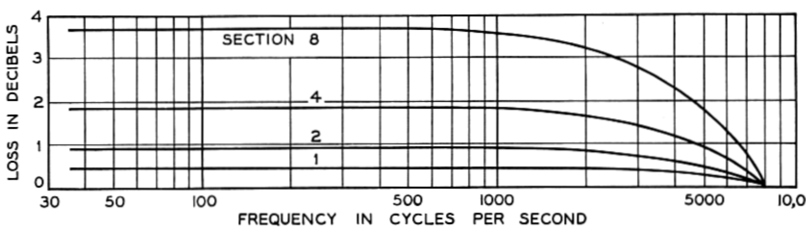

Fig. 8—Attenuation correction furnished by high-frequency equalizer.

Section 1, as may be noted, furnishes about ½ db attenuation correction. Section 2 is double that of Section 1, Section 4 is four times that of Section 1 and Section 8, eight times that of Section 1. These sections may be used in tandem so that attenuation correction for the high frequencies is, therefore, provided in steps of ½ db from zero to 7½ db.

An illustration of how the equalizers introduce the necessary attenuation correction is given on Fig. 9. The lower curve on this figure shows the loss of a 300-mile section of 165-mil circuit. The losses introduced by the particular sections of low and high-frequency equalizers that

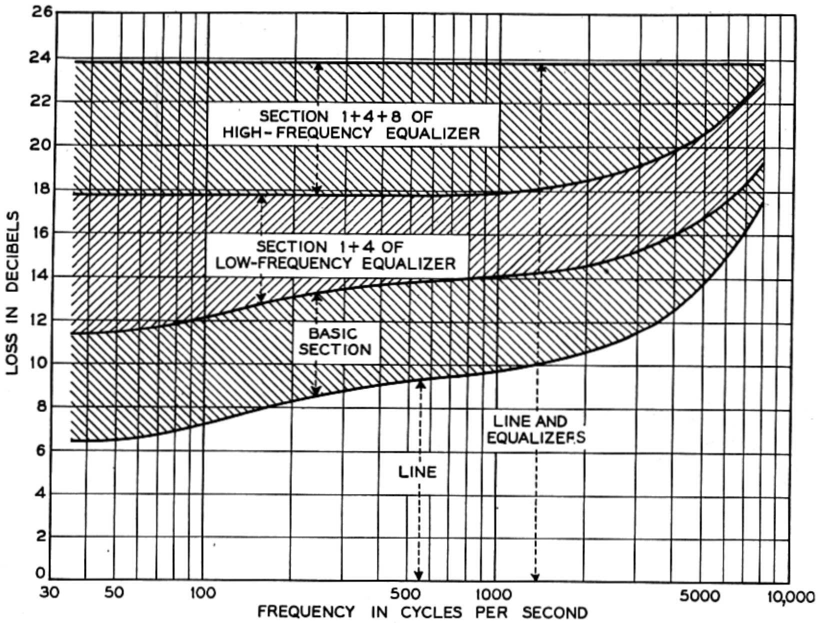

Fig. 9—Loss of 300-mile line section and associated equalizers.

would be required for this length of line are indicated by the cross-hatched areas, and the total line and equalizer loss is shown by the top horizontal line. Sufficient gain is introduced by the line amplifier to annul this loss.

Amplifiers

Two types of amplifiers are provided, one of which is used as a line or monitoring amplifier and the other which is used as a means for transforming one circuit into several circuits so as to feed various branches at points required.

For certain combinations of program circuits as many as 50 amplifiers may be connected in tandem. This necessarily imposes severe requirements on the transmission performances of the amplifiers particularly with reference to flatness of gain-frequency characteristics and phase distortion. By designing the coils used in the amplifiers so as to have very high inductances the desired phase distortion requirements were met while at the same time the necessary flatness of gain characteristic was obtained at the low frequencies.

Figure 10 shows the transmission circuit of the line amplifier and monitoring amplifier. This device has a 600-ohm input and output impedance and consists of two stages of push-pull amplification. The potentiometer is a balanced slide wire having a continuous gain adjustment over a range of 6 db. A balanced input transformer serves to connect the potentiometer to the grids of the two push-pull vacuum tubes which function as the first stage of this amplifier. The first stage is connected to the second or power stage by means of resistance coupling which gives better results both as to phase distortion and low-frequency gain characteristics than if transformer or retard coil coupling were used. Resistances are provided in the grid circuits of the second stage so that the high-frequency characteristic may be adjusted as required. The power tubes are connected to an output transformer which has the unique feature of providing a monitoring outlet which is not materially affected by voltages produced at or beyond the line terminals. The transformer, as may be observed, consists of three balanced windings arranged as in the form of the well-known hybrid coil used in two-wire telephone repeaters, with the exception that the two low impedance windings are of unequal ratio, the line windings having many more turns than the monitoring windings. The ratio of the windings is such that the voltage at the monitoring terminals when said terminals are closed through 600 ohms is 30 db below the voltage at the line terminals. Resistances are inserted in series with the monitoring winding so that an impedance of 600 ohms will be presented at the monitoring terminals.

The average gain of the amplifier with the potentiometer set at its maximum position is 33 db. Of 100 amplifiers measured, the gain at 35 cycles averaged .10 db less than the gain at 1,000 cycles while from 100 to 8,000 cycles the gain was constant within .05 db. The delay at 50 cycles is approximately .6 millisecond greater than it is at 1,000 cycles. From 150 to 8,000 cycles the delay is substantially constant and is only a small fraction of a millisecond. The amplifier is capable of handling an output power 9 db above reference volume without noticeable distortion.

At several points along a program circuit taps or branches are provided so as to connect various broadcasting stations to the program circuit and also to connect to other program circuits which form part of a broadcasting network. Points where such connections or branches are made are commonly called bridging stations. At some points as

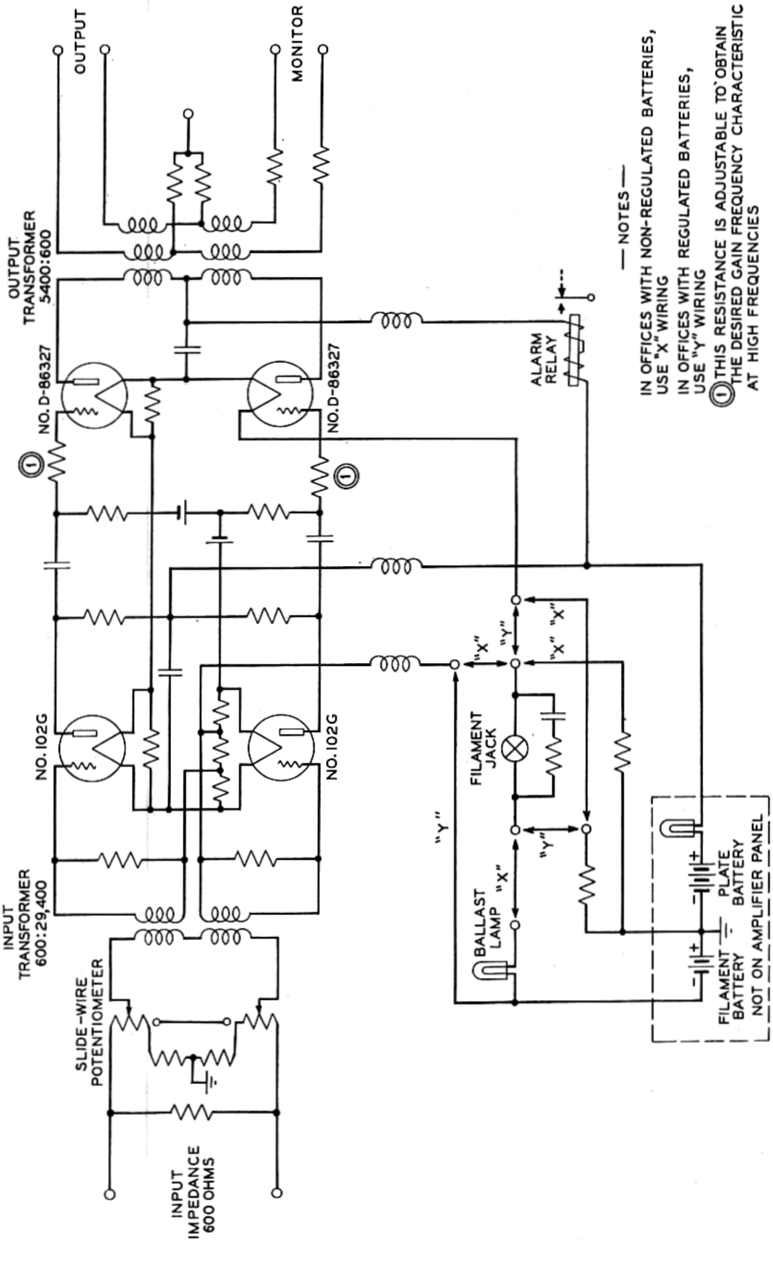

Fig. 10—Schematic of line amplifier.

many as six branches are supplied but generally only two or three taps are utilized.

To accomplish this branching out at a bridging station a resistance network multiple is provided, having six outlets. This network multiple is shown on Fig. 11. To annul the loss of the network a single stage amplifier is connected in front of it. This network multiple and amplifier are mounted on the same panel forming a single integral unit. The network multiple is so proportioned that if any one of the branches is accidentally opened or short-circuited the other branches are affected to only a minor degree. The amplifier is adjusted so that the gain from the input terminals to any of the output branches is zero. The bridging amplifier is normally inserted immediately in front of the line amplifier. As in the case of the line amplifier mentioned above, high inductance coils are utilized in order to keep phase distortion at a minimum. A resistance adjustment is provided in the grid circuit in order to adjust the high-frequency characteristic of this amplifier to the desired value.

The gain-frequency characteristic of the bridging amplifier is practically identical with the corresponding characteristic just described for the line amplifier, while the delay is even less.

Predistortion

The means utilized to accomplish the predistorted transmission referred to earlier includes the provision of a so-called predistorting network at the sending end of a program circuit and a restoring network in each branch which supplies a broadcasting station. The predistorting network introduces a large loss at low frequencies with a decrease in loss as the frequency is increased. By introducing suitable amplification immediately behind the predistorting network the resultant effect is to raise the high-frequency transmission relative to the low-frequency transmission by the difference in loss between the 1,000-cycle loss of the predistorting network and its higher frequency loss. The restoring network characteristic is the inverse of the predistorting network. These two networks are 600-ohm constant impedance type structures. The restoring network is shown schematically in Fig. 12. The predistorting network is generally similar to this, having different constants and a slightly different arrangement of elements. On Fig. 13 are shown the loss-frequency characteristics of the predistorting and restoring networks and a third characteristic which is the sum of these two. As may be noted this latter characteristic has a constant value throughout the frequency range.

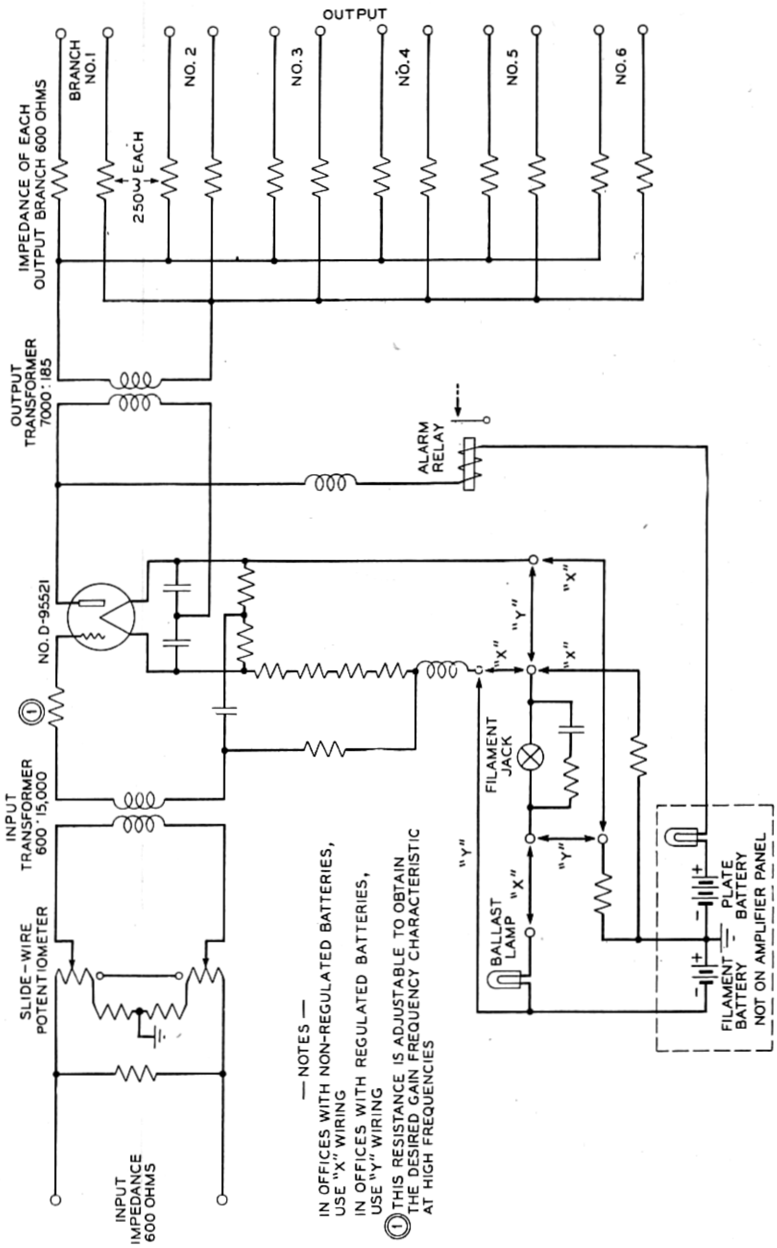

Fig. 11—Schematic of bridging amplifier.

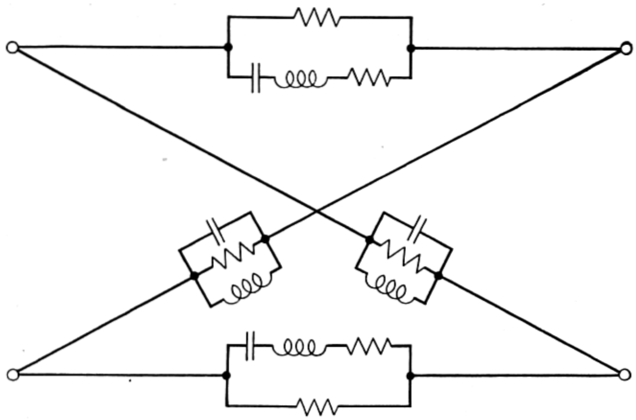

Fig. 12—Restoring network.

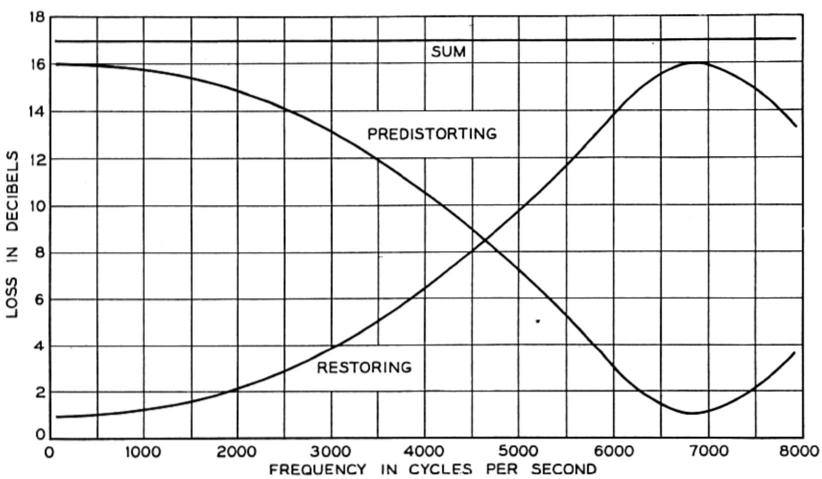

Fig. 13—Attenuation characteristics of predistorting and restoring networks.

Line Filters

As a rule, on open-wire circuits other transmission channels are provided on the same wires which carry the program transmission. These other channels operate at frequencies above the program range and in order to direct the various currents to their proper channels at a terminal or repeater station carrier line filter sets are inserted at the ends of the line wires. The carrier line filter sets include a low-pass and a high-pass filter. The low-pass filter, cutting off somewhat above 8,000 cycles, directs the program transmission to the program apparatus and the high-pass filter which has a low end cutoff around 9,000 cycles directs the carrier transmission to its associated carrier equipment. Attenuation frequency characteristics of these filters are shown on Fig. 14. The low pass filter is of unusual design and is described at some length in a companion paper.[3]

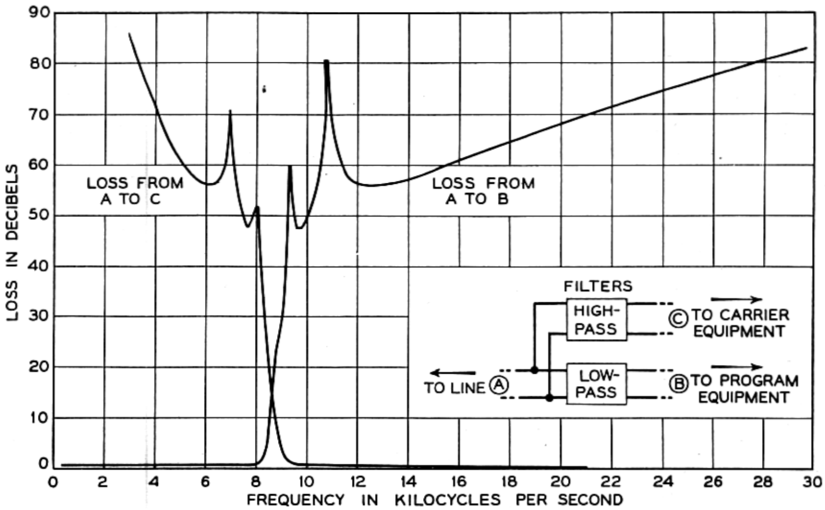

Fig. 14—Attenuation characteristics of line filter set.

Monitoring Features

A very important factor in the satisfactory operation of a program system is the provision of monitoring arrangements by which the operating forces are enabled to observe the quality of transmission, listen for extraneous interferences and observe indicating devices in order to make certain that the program is maintained at its proper volume.

Three types of aural monitoring facilities were provided on a trial basis for the new program system. The first type consists of a single unit loudspeaker operated by a suitable amplifier. With this loudspeaker system a good response characteristic from approximately 100 to 5,000 cycles is obtained, the low-frequency response depending, of course, on the size of the baffle used with the loudspeaker.

The second type of monitoring consists of two headset receivers arranged with a proper equalizing network circuit. This type of monitoring provides good response characteristics from approxi-

[3] A. W. Clement, "Line Filter for Wide-Band Open-Wire Program System," published in this issue of the *Bell Sys. Tech. Jour.*

mately 50 cycles to 8,000 cycles, enabling the observer to cover the entire program frequency range, thus permitting him to detect any extraneous interference which may be introduced even though this occurs at very low or very high frequencies.

The third type of monitoring consists of two loudspeakers and associated equalizing network with the loudspeakers mounted in a large baffle board. This arrangement affords a fairly uniform response from about 40 cycles to above 8,000 cycles. The particular type of monitoring which might be provided at the various stations would be governed by the service requirements involved.

To observe the volume on the program circuit, volume indicators are used. A new type of volume indicator was made available along with the new program system. This new device utilizes a full-wave copper oxide rectifier, has a much greater sensitivity range than that of the devices formerly used and possesses materially improved indicating characteristics. The volume indicator is connected across the monitoring terminals of the line amplifier, in which position it is bridged across a practically non-reactive 600-ohm impedance. Located thus it is also independent of line impedance affording more accurate results and obviating the necessity of correcting volume readings on account of line impedances. Also at this location it introduces no loss or phase distortion to the through program circuit.

The above constitutes a description of the major items employed in this program system. There are a number of other units, such as attenuators, repeating coils, etc., which will not be described in detail here but will be referred to as the need arises.

Typical Station Layouts

Due to the various requirements for different types of service and due in part to the different type of facilities, the general apparatus layouts and arrangements at different repeater stations are not always the same. Several of the more important general or typical layouts will be briefly discussed, however.

On Fig. 15 is shown a layout of a typical intermediate station where bridging is not required and where the gauge of the wires in the two directions is the same. As may be noted from this figure, switching facilities are provided so that the apparatus may be connected into the circuit so as to properly take care of either the east-west or west-east transmission. For this type of layout most of the apparatus is common to both directions of transmission. The fixed artificial lines or pads indicated by Note 1 on Fig. 15 are for the purpose of building out whichever line has the lower 1,000-cycle attenuation so that this

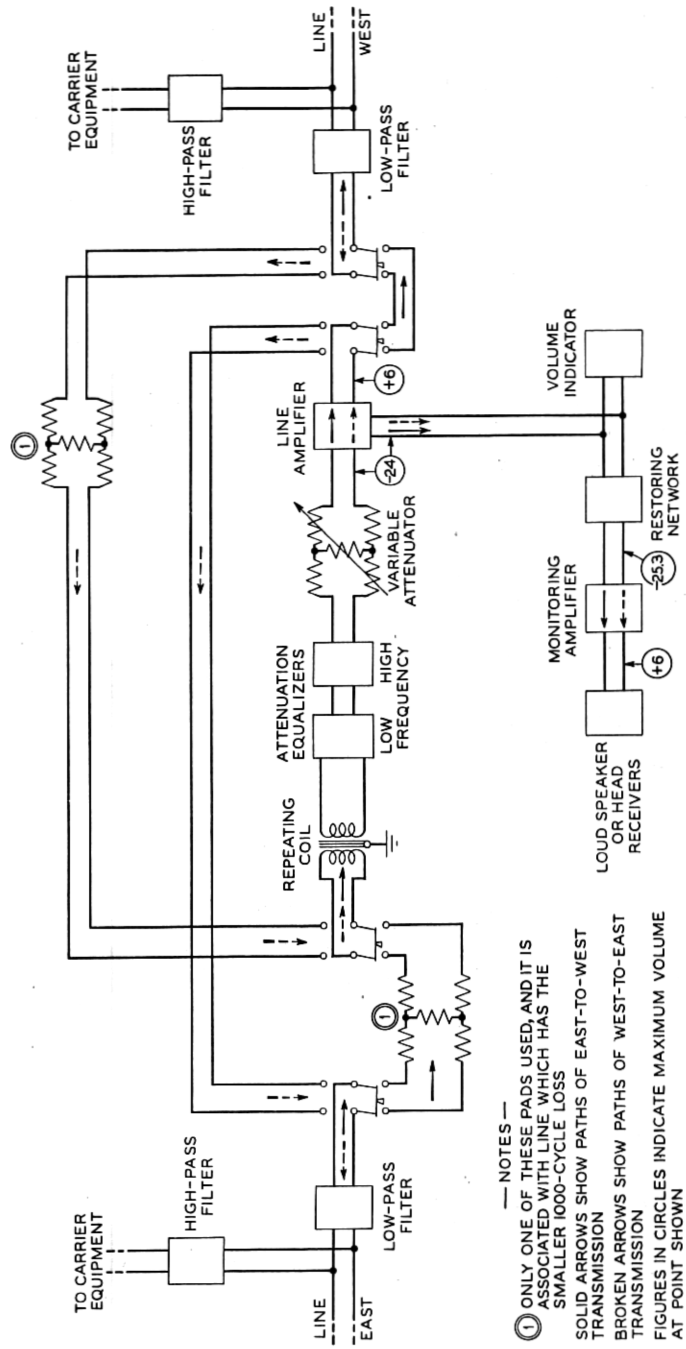

Fig. 15—Intermediate station layout.

line and associated pad will have the same 1,000-cycle loss as the other line. As indicated, only one of these pads is required. This building out of the shorter line minimizes attenuator adjustment when the direction of transmission is reversed. The line amplifier in this, as well as the other layouts to be discussed, is always set for a gain of 30 db.

On Fig. 16 is shown the layout of a typical intermediate non-bridging station where the gauges of the wires on the two sides of the repeater station are different. As mentioned earlier each gauge of wire has its own particular low-frequency attenuation equalizer. Consequently, where the gauges of the wires on the two sides of the repeater station are not alike, it is necessary to arrange the station layout so that the proper low-frequency equalizer will be associated with the proper direction of transmission. This association of apparatus may be readily observed from Fig. 16.

On Fig. 17 is shown the layout of a typical terminal station. This layout differs from the intermediate station layout largely in the fact that provision must be made for the introduction of predistortion when the terminal station is transmitting a program to the open-wire line and in the provision of a restoring network when the terminal station is receiving a program from the open-wire line. The general layout of the apparatus may readily be observed by reference to the figure. The monitoring facilities at this type of station, in general, differ from those provided at the normal intermediate station in that a two-unit loudspeaker is provided for use as desired.

On Fig. 18 is shown the layout of a typical intermediate bridging station where the gauge of the wires in the two directions is the same. This arrangement differs largely from the arrangement shown on Fig. 15 in that the bridging amplifier is inserted immediately ahead of the line amplifier so as to provide the necessary additional branches as required. The general circuit arrangements involved to take care of the different types of branches which may be encountered are indicated on this figure. The photograph, Fig. 19, shows the program equipment layout at an intermediate bridging station, which is of the type just discussed in Fig. 18, utilizing, however, only one branch circuit which is connected to a local broadcasting station.

In certain of the layouts just discussed, one apparatus unit designated as "Aux Filter" is shown which has not previously been mentioned. This is an 8,000-cycle low-pass filter somewhat similar to the low-pass line filter, except that it is not designed to operate in parallel with any high-pass filter. This filter is required at the transmitting and receiving terminals, in the branches feeding the radio station and

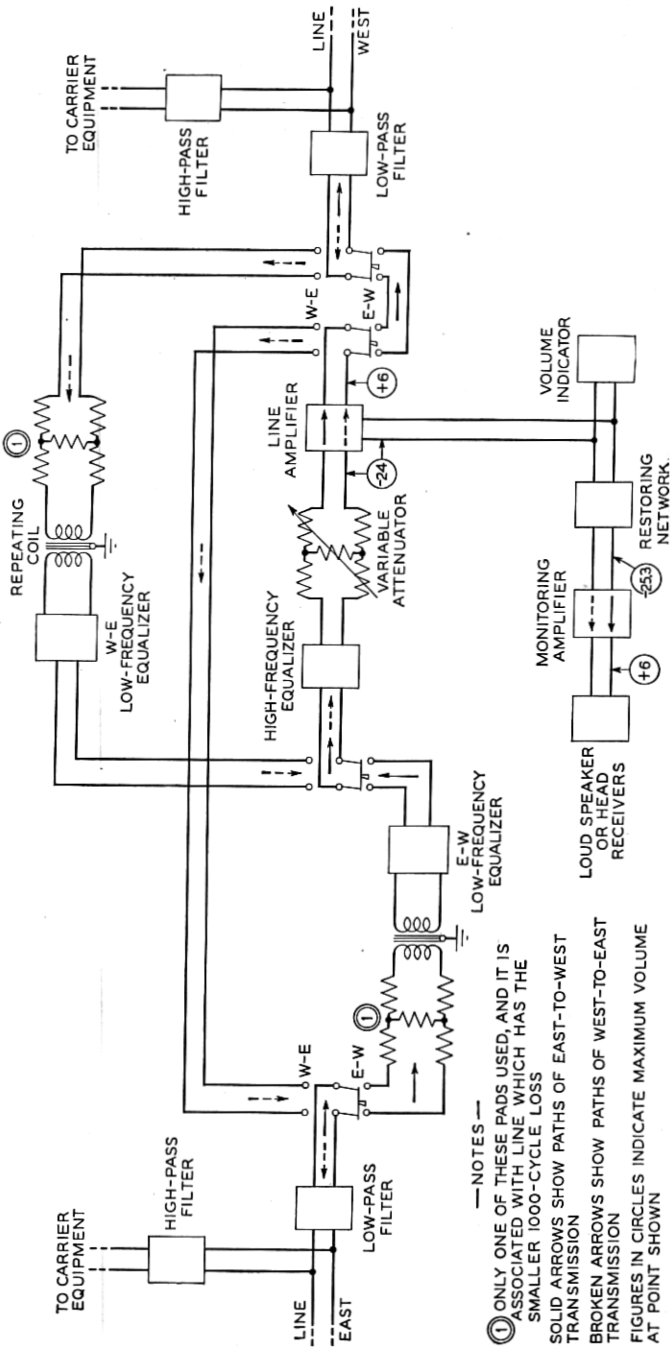

Fig. 16—Intermediate station layout; different gauges.

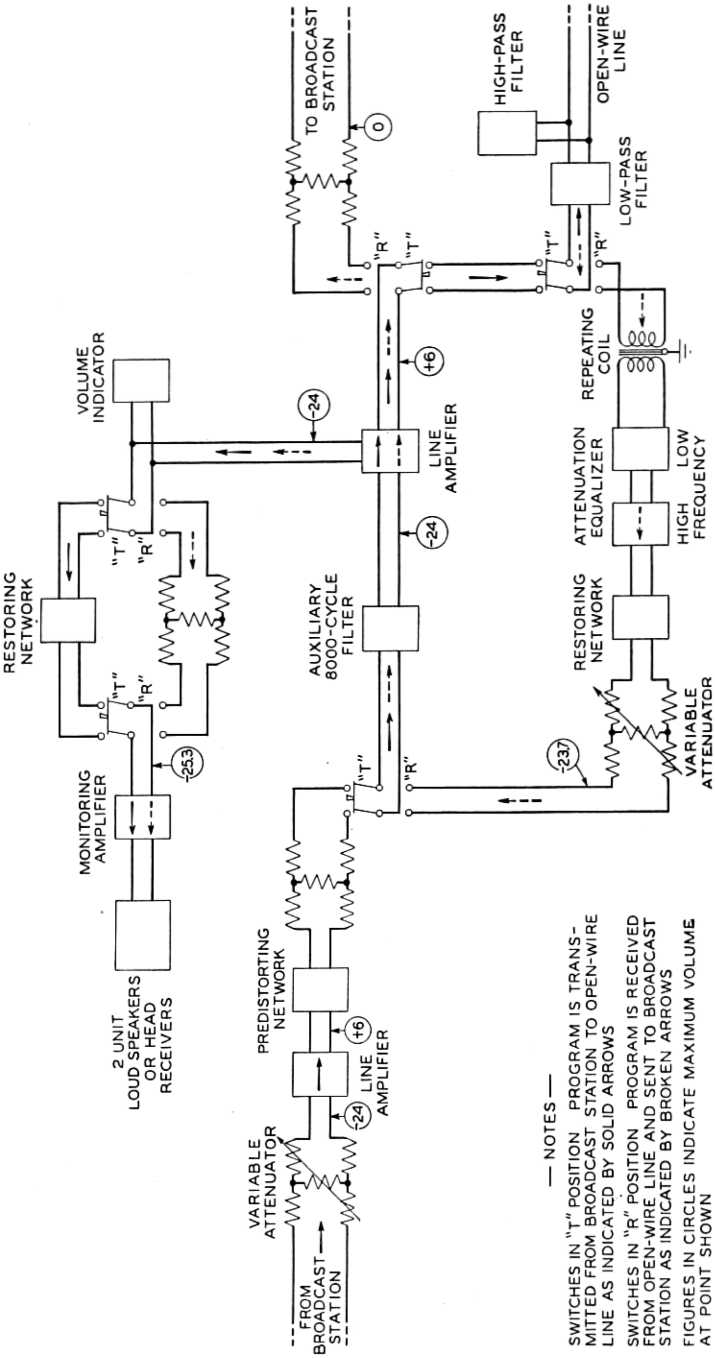

Fig. 17—Terminal station layout.

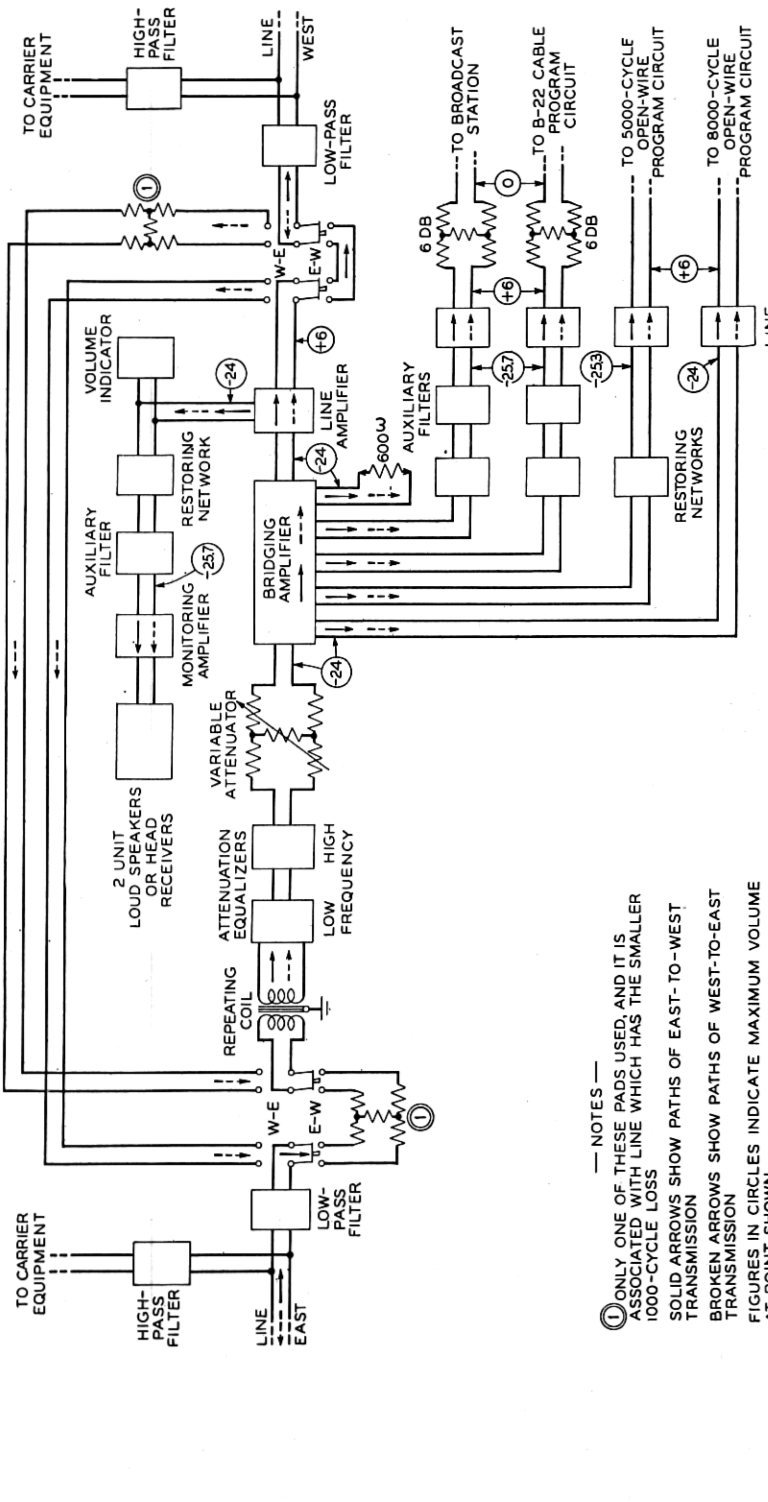

Fig. 18—Bridging station layout.

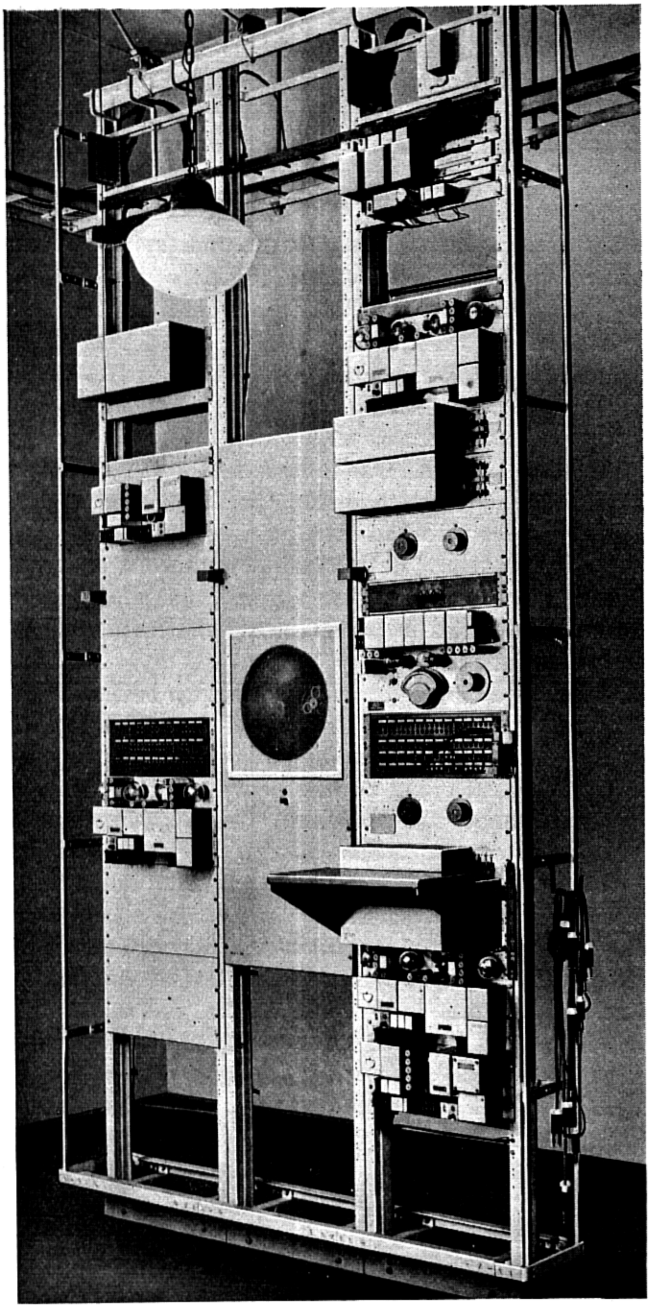

FIG. 19—Intermediate bridging station bay layout.

also in the high quality monitoring circuit to afford additional discrimination against unwanted high-frequency interference as, for example, interference from the carrier channels. This arrangement of splitting the filter requirements enables a less expensive type of line filter set to be employed.

Overall Performance

The initial application of this new program system was made on two transcontinental circuits between Chicago and San Francisco. One circuit, referred to as circuit 1, was routed through Omaha and Denver over the central transcontinental line. The other circuit, referred to as circuit 2, was routed via St. Louis and Kansas City to Denver and thence over the same pole lead as circuit 1. The layout of these two circuits is shown in Fig. 20. Circuit 1 was approximately 2,395 miles long and was routed through 17 repeater stations involving 23 amplifiers in tandem. Circuit 2 was approximately 2,689 miles long and was routed through 19 repeater stations involving 29 amplifiers in tandem. Both circuits were routed through B-22 cable facilities between Sacramento and Oakland, California, and non-loaded cable facilities in the transbay submarine cable between Oakland and San Francisco.

At San Francisco a listening studio was set up in the Grant Avenue office where the program circuits terminated. A two-unit loudspeaker with suitable connecting networks was set in a 7′ x 7′ baffle, the response of this loudspeaking system being practically uniform from about 40 cycles to above 8,000 cycles. The room in which the loudspeakers were located was acoustically treated so as to obtain the proper reverberation time. A powerful amplifier having a flat gain-frequency characteristic from 35 cycles to well above 8,000 cycles supplied the loudspeaker system. A high quality phonograph system for furnishing test programs was also installed at the Grant Avenue office. The records used were of the vertical cut type and included several recordings of a 75-piece orchestra as well as various solo and instrumental recordings. Two outside pickup points were used, one at the studios of one of the broadcasting companies at San Francisco and the other at a hotel. At both of these places the moving coil type of microphones was used and the latest type of high quality pickup amplifiers. The pickup system used at both these places had a response characteristic within about 2 db of being flat over the range of 35 to 10,000 cycles.

Figure 21 is a photograph showing the special equipment placed in the Grant Avenue office for carrying out the various overall tests and

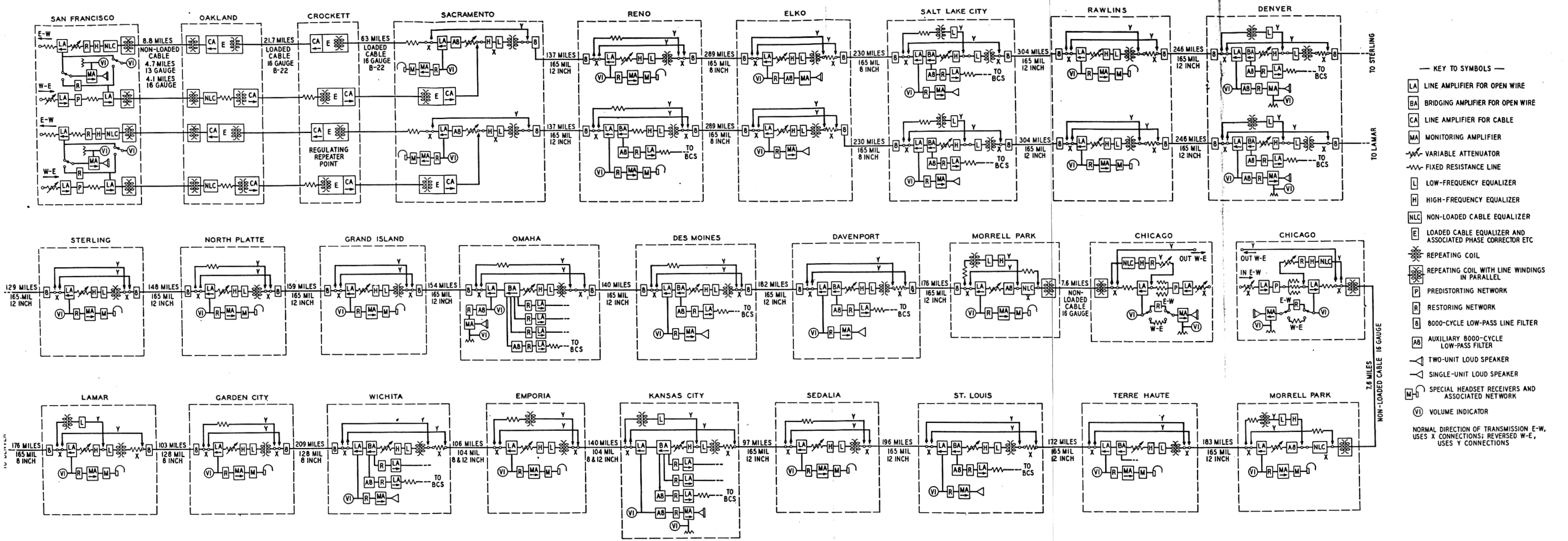

Fig. 20—Circuit layout for trial of wide-band open-wire program system.

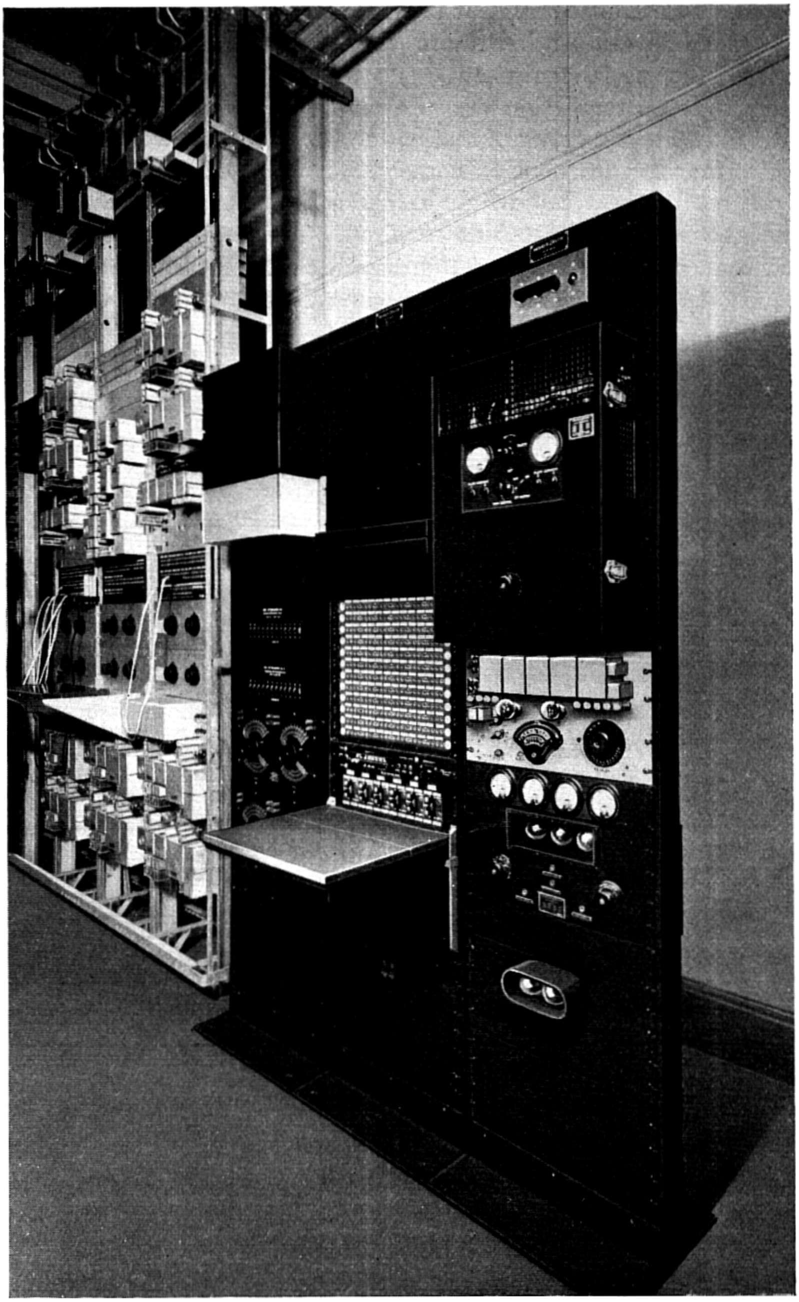

Fig. 21—Special apparatus bay layout.

also shows the new equipment provided at San Francisco on the two program circuits under discussion. The three right-hand bays accommodated the special equipment.

In making transmission measurements, the circuit under test was first split up in a number of sections and each section was then measured at four test frequencies, namely, 50, 100, 1,000 and 7,000 cycles. If the results were not within required limits the attenuators and equalizers were readjusted as required. The various sections were then connected together and the overall circuit measured at several frequencies. Figure 22 shows the transmission-frequency characteristics of circuit 1. The solid line is the average of nine measurements while the dashed lines show the extreme deviations obtained for any of the nine measurements. Figure 23 shows corresponding data for circuit 2. For comparison purposes the average characteristics of the two circuits separately and the two of them connected in tandem making a loop circuit of over 5,000 miles are shown on Fig. 24.

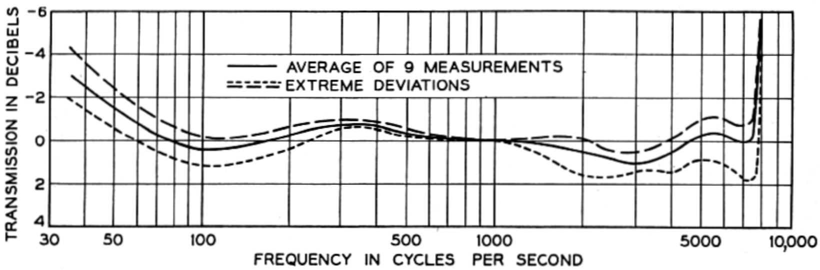

Fig. 22—Transmission frequency characteristics of circuit No. 1, Chicago to San Francisco.

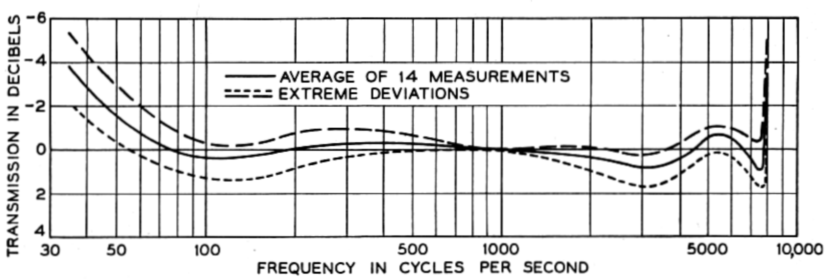

Fig. 23—Transmission frequency characteristics of circuit No. 2, San Francisco to Chicago.

Other measurements were made to determine whether non-linear effects were produced. For example, two frequencies were applied to the circuit, one being measured and the other alternately cut off and on to determine whether one frequency adversely affected the transmission of the other or produced undesirable sum and difference products. Such distortion effects were found to be small. Measurements were made to determine whether the overall transmission varied with the load applied. With a testing power which was varied in magnitude from 50 milliwatts to .1 milliwatt, the transmission varied slightly more than 1 db, that is, with the heavy load the circuit loss was somewhat more than 1 db greater than at the light load.

A noise and crosstalk survey was made on these program circuits and on message circuits on the same pole lead. Observations were made at the terminals of the message circuits while a program was being transmitted on the program circuits to determine the amount of

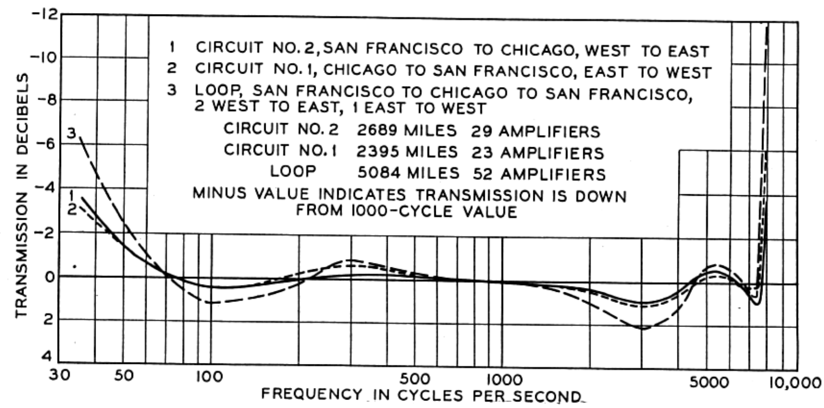

Fig. 24—Average transmission frequency characteristics.

interference introduced into the message circuits from the program circuits, and, conversely, observations were made on the program circuits while various paralleling message circuits were in use, and the resulting interference was recorded.

The noise or crosstalk volume on the program circuits was measured by means of a volume indicator, which had inserted between it and the circuit at the point of measurement a network having a loss-frequency characteristic such that the various frequencies affecting the meter reading were attenuated or weighted in much the same way that the ear weights the different frequencies. Crosstalk volume and noise on the message circuit were measured with an indicating meter in much the same manner except that the network used here had an attenuation frequency characteristic corresponding very nearly to that of the ear and an average telephone set. The network used on the program circuits was referred to as a "program weighting network," while that used with the message circuit was the ordinary "message weighting network." The noise and crosstalk volume was then recorded in db referring to reference noise with either program weighting or message weighting. Reference noise is that amount of interference which will produce the same meter reading as 10^{-12} watt of 1,000-cycle power, which is 90 db below 1 milliwatt.

The results of this survey indicated that in consideration of the layout and levels of the existing message circuits and of the noise existent on these circuits and on the program circuits, the value for maximum program volume, should, under normal conditions, be + 3 referred to reference volume; that is, at this value the best balance between program to message crosstalk and program circuit noise would result. It was also determined that on very long sections, or on sections where all circuits were subjected to severe noise exposure, the maximum volume on the program circuits could be increased 3 db to improve the signal-to-noise ratio on the program circuits. This higher volume could be permitted in these cases since on the longer sections the message circuits also usually operate at higher levels, and on the especially noisy short sections the increased crosstalk to the message circuits will ordinarily be masked by the greater noise.

The average noise measured at San Francisco or Chicago at the circuit terminals at the reference volume point was 49 db above reference noise "program weighting" when the restoring network was included at the receiving terminal. The noise averaged 5 db higher than this with the restoring network removed. This value of noise is about 43 db below the maximum power of the program measured at the same point with the same measuring instrument. This, therefore, establishes a signal-to-noise ratio of about 43 db, thus permitting a volume range of approximately 40 db.

The various tests referred to gave statistical data concerning the transmission performance of the circuits from which it could readily be predicted that the circuits would transmit programs with very little impairment to quality. To substantiate this, very critical listening tests were made, comparing the quality of a program after it had been transmitted over various length circuits with the same program transmitted over a reference circuit which was distortionless over the frequency range for which the circuits were designed, namely, to 8,000 cycles. Figure 25 shows schematically the terminal arrangements employed at San Francisco for these listening, or, as they are more commonly called, comparison tests.

Various types of programs were used, such as speech, vocal and

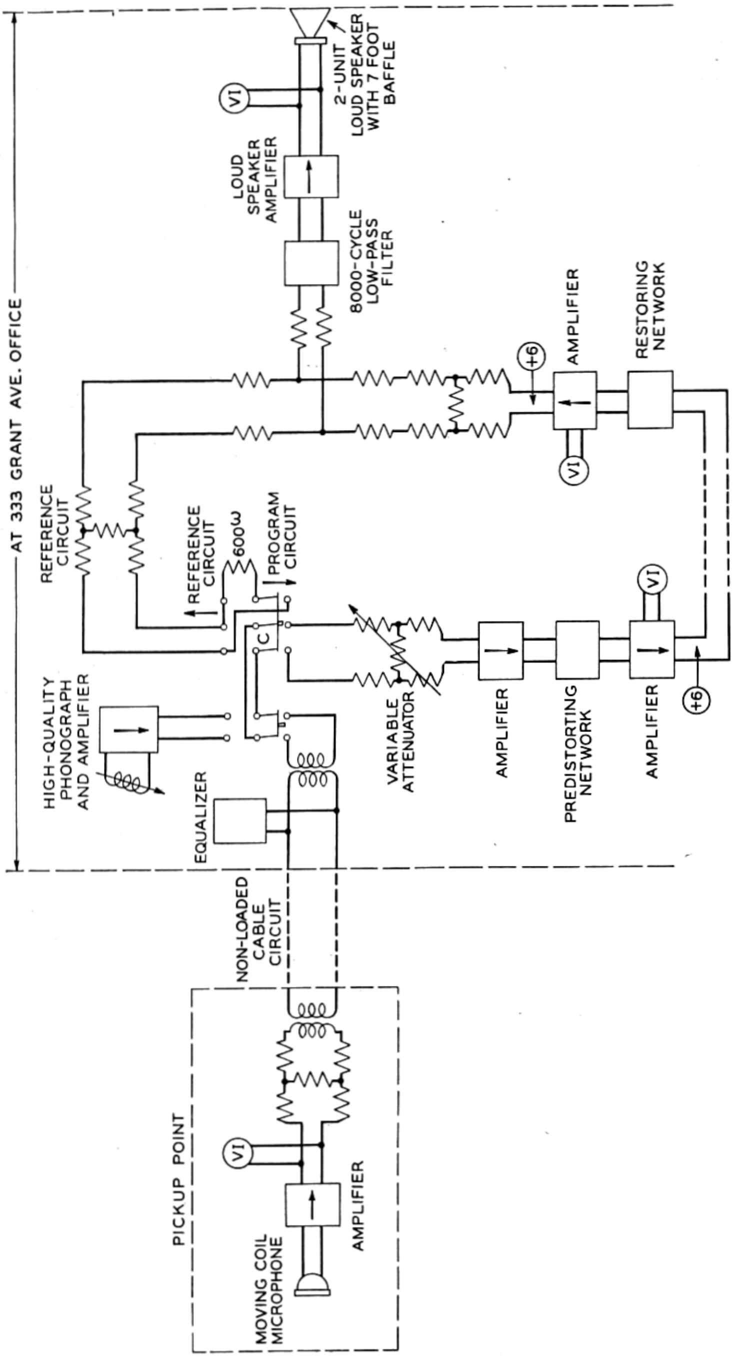

Fig. 25—Terminal arrangements at San Francisco for comparison tests.

instrumental selections, orchestral renditions, both classical and jazz. Quite a number of observers were employed, some of whom were present on several tests and a few on all tests. On tests made on a San Francisco–Denver–San Francisco loop involving 2,600 miles of circuit, no observer was able to consistently differentiate between the quality over the reference circuit and that over the program circuit. On tests made on the San Francisco–Chicago–San Francisco loop certain of the more experienced observers were able to differentiate between the circuits somewhat more than 50 per cent of the time, but this, it must be remembered, was on a direct comparison test. None of the observers could tell with any assurance which was the program circuit and which was the reference circuit if a few minutes were allowed to elapse between switches. On the Chicago loop 264 observations were made on direct comparison tests on which 60 per cent of the observations favored the reference circuit and 40 per cent favored the program circuit.

Included as part of the overall program, were tests to determine the volume range, maximum volume obtainable and speed with which the circuits could be reversed.

On the volume range tests a source of program was obtained and so regulated that it had a very narrow volume range. This was then applied to the circuit with the sending end gain adjusted so that the maximum volume applied at the repeater outputs was + 6. The sending end gain was then gradually decreased so as to apply a gradually decreasing volume to the circuit. This process was continued until the program volume was so weak that the line noise interfered with its satisfactory reception. The amount that the sending end gain was adjusted determined the volume range. The average value for several tests was slightly in excess of 40 db. The maximum volume was determined by switching a 10 db pad from the sending end to the receiving end of the circuit and listening to a transmitted program, noting the point at which there was a quality difference between the high volume and low volume condition. It was found that a slight difference could be detected when the maximum volume on the high volume condition was + 10, thus showing the circuit was capable of handling a maximum volume slightly lower than this value.

As mentioned earlier, switching means are provided at each station for reversing the direction of transmission. On the initial field tests it was demonstrated that the circuits could be reversed readily and at the same time maintain satisfactory overall characteristics. At the present time, on receipt of proper advance notice, the circuits are being reversed on commercial programs in approximately 30 seconds.

Conclusion

The above development provides a program transmission system applicable to open-wire lines which even for very long distances will provide transmission characteristics which should be adequate for program transmission for a number of years to come.

Acknowledgment

The author makes grateful acknowledgment to his associates in the Bell Telephone Laboratories, to members of the Long Lines Department of the American Telephone and Telegraph Company, and of the Pacific Telephone and Telegraph Company, for their cooperation in connection with the setting up of the circuits and participation in many of the tests, and to the National Broadcasting Company and the Columbia Broadcasting System for their assistance in making available the program pickup sources at San Francisco.