Long Distance Cable Circuit for Program Transmission *

By A. B. CLARK AND C. W. GREEN

The rapid growth of the telephone cable network in this country has made it desirable to develop a system whereby this network may be utilized to transmit programs for broadcasting stations over distances upwards of 2,000 miles. Such a system has recently been developed and given a trial on a looped-back circuit 2,200 miles long with very satisfactory results. It transmits ranges of frequency and volume somewhat in excess of those now handled by the open-wire circuits which are used for program work, and also in excess of those handled by present-day radio broadcasting systems when no long distance lines are involved.

The paper deals first with the transmission requirements of broadcasting systems and then gives a description of this new cable system.

AS discussed in two recent papers,[1] one of which was presented before this Institute, telephone circuits are now extensively used for chain broadcasting. Radio broadcasting stations covering various local areas in the United States are connected together by wire circuits so that programs are delivered simultaneously to all of them. Thus, it is possible to deliver a program to the whole nation at once. About 35,000 miles of telephone circuits are now being regularly utilized for this service and about 150 radio broadcasting stations receive programs from one or more of the chains of wire circuits.

Today practically all of this service is being furnished by means of open wires using voice-frequency channels. Long distance cable routes are growing rapidly and are supplementing the open-wire routes, particularly those carrying very heavy traffic. Fig. 1 shows the long distance cable routes now in use in the United States, together with the additional routes proposed for installation within the next few years. The advantages in placing some circuits in these cables which will adequately handle program transmission service were evident and led to the development described in this paper.

Because of the special characteristics which program transmission circuits must possess it was necessary to develop an entirely new type of cable circuit, in which the method of placing the wires in the cables, the type of loading and all of the apparatus, including amplifiers and distortion correcting apparatus for both amplitude and delay, differ radically from other cable circuits. The development was recently completed and a trial installation made in which wires were looped

[1] F. A. Cowan, "Telephone Circuits for Program Transmission," presented at Regional Meeting of S.W. District of A. I. E. E., Dallas, Texas, May 7–9 1929, *Proceedings of A. I. E. E.*, July, 1929, A. B. Clark, "Wire Line Sys tems for National Broadcasting," presented before the World Engineering Con gress at Tokio, Japan, October, 1929, *Proceedings of I. R. E.*, November, 1929 *Bell System Technical Journal*, January, 1930.

* Presented at Convention of A. I. E. E., Toronto, June, 1930.

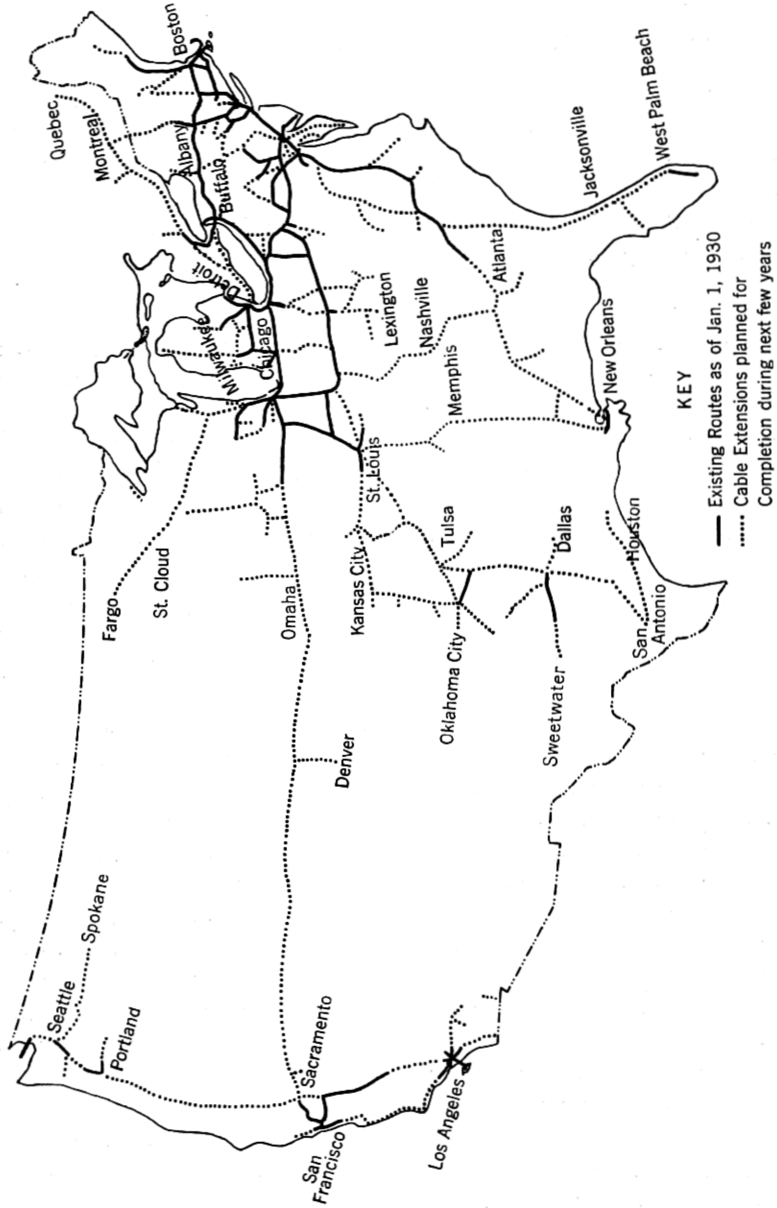

Fig. 1—Main toll cable routes of United States and Canada.

back and forth in the cables between New York and Pittsburgh so as to produce a circuit 2,200 miles in length. Tests were made on this circuit over a period of several months and very satisfactory results were obtained. It is, therefore, planned to make extensive application of this system and eventually program circuits may be provided in cable over practically all of the long toll cable routes.

So as to appreciate what is involved in the design of this system there will first be presented a discussion of the transmission requirements. Following this, the new system will be described and its more important transmission characteristics set forth.

Transmission Requirements

For program transmission the ideal, of course, is to provide a transmission line such that no distortion whatsoever will be caused to program material transmitted over the line whatever be its length. Ideally also, program pickup apparatus, radio transmitters, radio receivers and loudspeakers should be such that the program delivered from the loudspeaker should sound exactly like the original program delivered to a direct listener in the best location. To meet this ideal, however, would require that the whole audible range of frequencies, extending from about 20 to 20,000 cycles, and a tremendously wide range of volumes representing power differences of more than a million-fold be handled without any distortion whatsoever.

Actually the radio art is far from attaining this ideal. It does not seem reasonable, therefore, to provide lines very much superior in transmission performance to the rest of the system since this would unnecessarily increase the cost for providing the service. However, telephone lines represent a fixed investment which must remain in service for many years in order to keep costs within reason and, furthermore, it is, in general, not practical to change the transmission characteristics of the lines once they have been installed. It is, therefore, necessary to take into account the fact that the broadcasting art has considerably improved in the past and is likely to improve in the future and provide telephone lines of sufficiently good characteristics to anticipate the improvements which are likely to come within a reasonable period of time.

These general considerations have led to the adoption of the following as practical standards of performance for the new cable system:

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

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

Some of the more detailed considerations which have led to the setting of these standards will now be given.

Frequency Band

Figure 2 gives some data in regard to the frequency range required for different musical instruments as well as speech. These data were obtained in the Bell Telephone Laboratories using an arrangement capable of picking up and reproducing practically the whole audible frequency range. Certain very low-frequency instruments, such as organ pipes and bass drums, were not included in the tests owing to laboratory limitations. A number of observers listened to the reproduced material, first, when practically the whole frequency range was transmitted and, second, with either the high frequencies or low

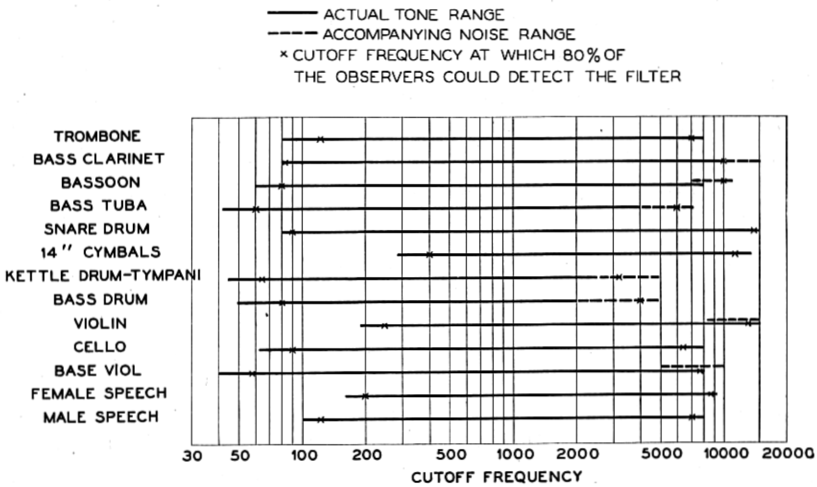

Fig. 2—Summary of important ranges required for different instruments.

frequencies cut off by means of filters. The observers endeavored to note whether there was any perceptible effect when the filters were introduced but did not attempt to determine whether introducing the filters made the reproduced material sound more or less pleasing.

Referring to the figure, it will be noticed that at the lower frequencies little appears to be lost by cutting off frequencies below about 50 cycles. At the upper frequencies, however, with certain of the musical instruments something is lost by cutting off frequencies above 8,000 cycles. Hissing sounds, sounds of a percussion nature and sounds of jingling keys, rustling paper, etc., appear to be most affected by cutting off the high frequencies.

Tests have shown, however, that when the frequency range 50 to

8,000 cycles is transmitted with very little distortion within the band the results obtained are very pleasing. The ordinary observer without making direct comparison tests is unlikely to detect the absence of the higher frequencies.

From the standpoint of radio transmission there will probably be some difficulties in handling the 8,000-cycle range which has been tentatively set as a standard for the cable line. Each radio station, theoretically at least, is now being allowed only a 10,000-cycle band of frequencies and, since both sidebands are transmitted, each band is fully occupied when transmitting 5,000 cycles. Since adjacent frequency ranges are not assigned to stations in the same locality, a certain amount of spreading out is, no doubt, tolerable, so that those listeners who are close to broadcasting stations should, in general, be able to pick up the 8,000-cycle range without undue interference from other stations. The more distant listeners will have trouble if their sets take in the complete 16,000-cycle band required to handle, on a double-sideband basis, the 8,000-cycle program range. Letting in this wide frequency range will bring in increased interference from other stations and will also increase the atmospheric interference.

In spite of this increased trouble which the distant listeners will have, it can no doubt be argued that it will do little harm for the radio stations to put out the full 8,000-cycle band. The nearby listeners, if they have very good sets, will in general be able to appreciate this, while the distant listeners, if their sets are arranged to receive only a 5,000-cycle band, should receive only slightly more interference from wide-band stations occupying adjacent frequency bands.

Evidently, if the frequency range were doubled so as to furnish the listener with practically the whole audible range of frequencies, these radio difficulties would be exaggerated. It seems certain that, if radio stations were to handle the whole audible band of frequencies, a reassignment of frequency bands to these broad-band broadcasting stations would be called for and also quite probably these radio stations would be forced to resort to single sideband transmission.

It is not sufficient merely to fix the limits of the frequency band. Limits to the allowable distortion within it must be established. Tests have indicated that it is desirable that different frequencies within the transmitted band should not suffer attenuations differing by more than about 5 db corresponding to power differences of about three-fold.

The transmission delay* suffered by different portions of the fre-

* "Delay" as used in this paper has the same significance as "envelope delay" used in literature on phase distortion. It is defined as $d\beta/d\omega$ where β is the phase shift and ω is 2π times the frequency.

quency band must also be considered. This is necessary because, when transmission over long distance lines is involved, this delay tends to be different for different parts of the frequency band and the distortion produced is a function of the frequency-delay characteristics. Tests have indicated that the high frequencies, say those in the range 5,000 to 8,000 cycles, should not suffer delay in transmission over the line more than 5 to 10 milli-seconds greater than the delay suffered by frequencies in the neighborhood of 1,000 cycles. However, at the low end of the scale more delay may be tolerated: for example, 50 cycle waves may be delayed as much as 75 milli-seconds more than those in the neighborhood of 1,000 cycles without noticeable deterioration in quality.

Requirements must also be imposed as to "linearity" of the transmission, that is, constancy of efficiency with different current strengths. If the transmission departs too much from "linearity" several disagreeable effects may be produced: (1) Spurious frequencies which are by-products of the true frequencies will become large enough to be annoying, (2) strong sounds will not be reproduced as well as weak sounds, and (3) when weak sounds are transmitted along with strong sounds the strong sounds will tend to obliterate the weak sounds.

In the design of this program transmission circuit the criterion was adopted that transmission put over the circuit at the maximum prescribed volume level must not sound appreciably different than transmission put over the circuit at a considerably lower level, at which lower level the non-linear distortion is negligible.

Volume Range

A favorably-seated listener to a high-grade orchestra is treated to a wide range of volumes. Opinions differ as to just how wide a volume range can be appreciated by such a listener, but it seems certain that it is at least 60 db, corresponding to a power range of one million to one. The human ear can hear volume ranges in excess of 100 db, corresponding to a power range of ten billion to one. For loudspeaker reproduction it has been found that a room must be particularly quiet in order to be able to appreciate a volume range of 60 db. Rooms in three-quarters of the usual residences are probably too noisy for a volume range as great as this to be appreciated. A 40 db volume range, corresponding to a power range of 10,000 to 1, can be appreciated in most rooms where radio listening is done and is quite satisfactory for most musical selections.

From the standpoint of design, the maximum volume of a wire program transmission system is limited by the requirement that the program must not be allowed to spill over unduly as crosstalk into neighboring circuits which may be carrying telephone messages or other programs. The volume may also be limited by the requirement that serious non-linear distortion be not introduced by effects produced in the vacuum tubes of the amplifiers or in any magnetic-core coils either in the apparatus or in the line. On the other hand, the minimum volume which a wire program circuit can handle is limited by the tendency of the noise present on the circuit to annoy the listener when the program volume is very weak. Crosstalk from other circuits into the program circuit also enters as an important consideration, since radio listeners must not be able to pick up intelligible conversations during those times when the program volume is very weak or when actual pauses occur in the programs.

From this, it is seen that the matter of widening the volume range of a wire program transmission system involves not only added cost to keep non-linear distortion and noise within limits but also, and perhaps even more important, added cost to isolate the circuit from other circuits on the same route.

From the standpoint of the radio part of broadcasting systems handling very wide volume ranges also presents difficulties. Radio transmitter and other radio equipment noises become more serious as the volume range is widened. More important, however, widening the volume range without corresponding increase in the radio transmitter capacity reduces the effective range of a radio broadcasting station, since this increases the tendency for the faint parts of the programs to sink below the level of atmospheric and receiver-set noises.

At present it is understood that most radio broadcast programs where no long distance wire circuits are involved are being delivered with a volume range of about 30 db.[2] In order to anticipate improvements which may come in the broadcasting art, however, it has seemed desirable to provide wire circuits in cable which will handle a wider volume range than this and, accordingly, 40 db has been taken as a working standard. This volume range appears to satisfy almost everybody with the possible exception of some who listen to broadcasts of symphony orchestras and the like. With the present limitations of volume ranges to about 30 db, there has been some complaint that much of the artistic quality and effectiveness of broadcasts of such high-grade music has been lost because of the fact that the operator manipulating the volume range control seemed to reduce the range an undue amount.

[2] O. B. Hanson, "Volume Control in Broadcasting," *Radio Broadcast*, March, 1930.

Studies are now under way looking toward systems which will compress the volume range transmitted over the line and expand it at the far terminal, but possible applications to radio systems may be difficult since receiver characteristics need to be considered.

If some volume range compression and expansion system is not employed, ability to handle a materially wider volume range can only be obtained with considerable difficulty. In the radio part of systems it will require reductions in radio transmitter noises and involve loss in the effective range of radio stations, unless higher powered transmitters are employed. In the wire part of systems it may involve the use of amplifiers and loading coils capable of handling more power, means for materially reducing the crosstalk coupling between circuits and also means for making the program transmission circuits more quiet.

Description of New Cable System

In this program transmission system the nominal telephone repeater spacing of 50 miles, common with message telephone circuits, is retained. The pilot-wire regulator system which compensates for changes in transmission caused by temperature changes in message circuits is also used for the program circuits.[3] The diagram in the top part of Fig. 3 shows several hundred miles of program transmission circuit, illustrating how it is divided up into repeater sections and pilot-wire regulator sections and also indicating the principal pieces of equipment located at the repeater stations.

As indicated on the diagram of Fig. 3, there are two classes of repeater stations, known as regulator stations and non-regulator stations. At the non-regulator stations the repeater gains are maintained at fixed values while at the regulator stations they are varied under control of the master pilot-wire regulating mechanism in such a way as to compensate for the transmission variations of the cable conductors caused by temperature changes.

At each non-regulating repeater station are placed:

1. An attenuation equalizer which corrects for the attenuation differences at different frequencies (at average temperature) introduced by the preceding repeater section.
2. A delay equalizer which corrects for the difference in delay at different frequencies introduced by the preceding cable section.
3. A one-way amplifier introducing sufficient gain to overcome the line loss, together with the added losses introduced by the attenuation and delay equalizers.

[3] A. B. Clark, "Telephone Transmission Over Long Cable Circuits," *A. I. E. E. Transactions*, Vol. 42, Feruary, 1923.

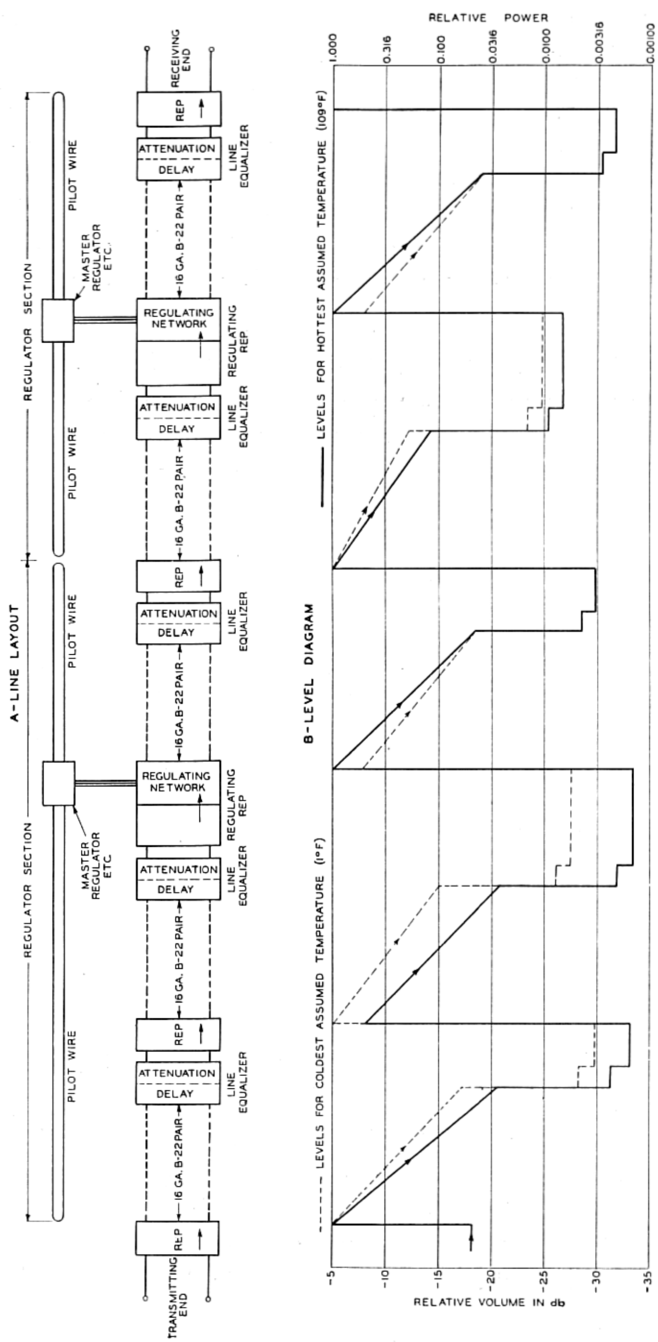

Fig. 3—Typical line layout and level diagram for B-22 program transmission system.

At the regulating repeater stations the arrangement is the same as at the non-regulating stations, except that another stage is added to the amplifiers. This stage includes a potentiometer associated with relays controlled by the master pilot-wire mechanism, the whole being arranged so as to compensate for the changes in transmission loss of the cable pairs caused by temperature changes.

In the lower part of Fig. 3 is shown a transmission level diagram, from which can be noted the losses and gains introduced by the different parts of the system, for a frequency of 1,000 cycles.

Cable

The transmission paths are provided by means of 16 B. & S. gauge non-phantomed pairs having a capacitance of 0.062 microfarads per

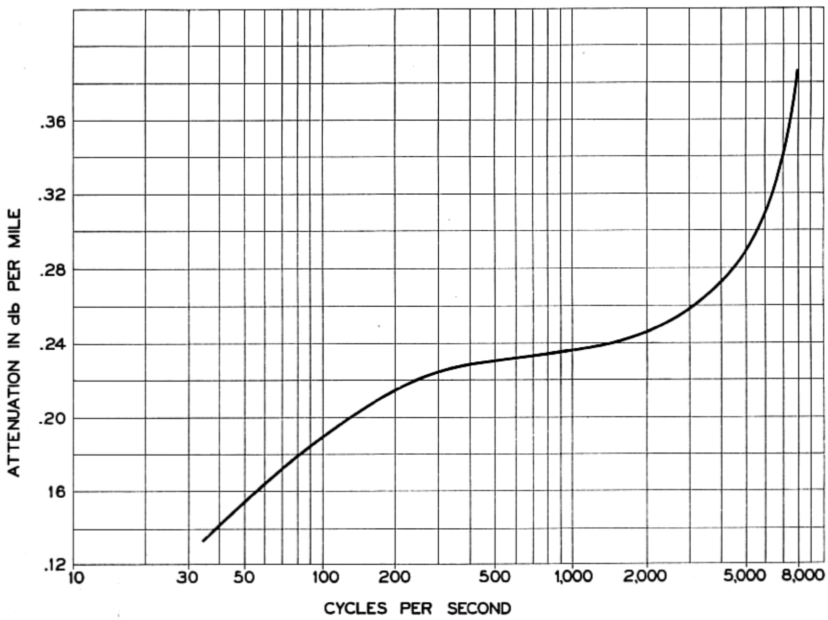

Fig. 4—Attenuation-frequency characteristic for 16-ga. B-22 cable pairs at 55° F. terminated in characteristic impedance.

mile. These pairs are loaded with 22-milhenry inductance coils spaced 3,000 feet apart. Present long distance message telephone circuits in cable have loading coils spaced 6,000 feet apart. The nominal cutoff frequency of the new circuit is about 11,000 cycles, permitting effective transmission of a frequency band extending up to about 8,000 cycles.

The nominal impedance is about 800 ohms and the attenuation per mile, at 1,000 cycles and average temperature, about .24 db. Fig. 4

shows the attenuation at average temperature plotted as a function of frequency, while Fig. 5 shows the line impedance.

Figure 6 shows how the cable circuit attenuation varies with temperature at different frequencies. As will be seen from the curves, temperature change produces effects not only in the series losses but also in the shunt losses. The series losses are changed largely because

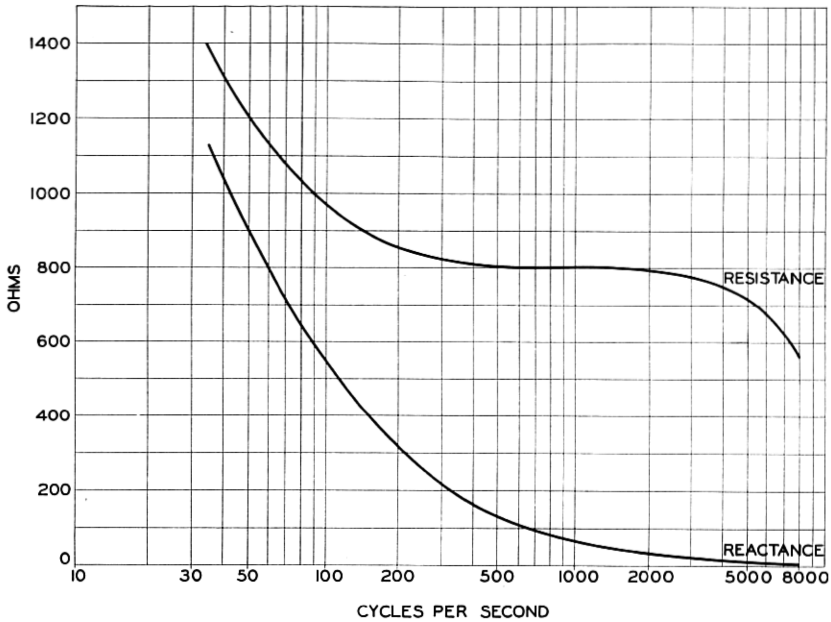

Fig. 5—Mid-coil characteristic impedance for 16-ga. B-22 cable pairs at 55° F.

the resistance of the copper cable conductors changes with temperature, and to a smaller degree because of changes in effective resistance of the loading coils. The shunt losses change with temperature due largely to changes in the conductance losses and, to a lesser extent, changes in the cable capacity with temperature. The conductance loss is approximately directly proportional to frequency so that it has maximum effect at the highest frequency. The effect of temperature on the conductance loss is opposite to the effect of temperature on the series loss so that increase of temperature reduces the shunt loss.

The matter of securing the necessary electrical separation between the 16-gauge program transmission circuits and the other circuits contained within the same lead sheath involved particular study. The use of shielded pairs was considered. Such use of shields, however, would very greatly increase the space occupied by each program circuit and, therefore, considerably increase the cost. By careful design of the cable and control of methods of splicing, it was found possible to avoid the use of shields. It was not found practicable, however, to make use of the phantom possibilities on the program pairs.

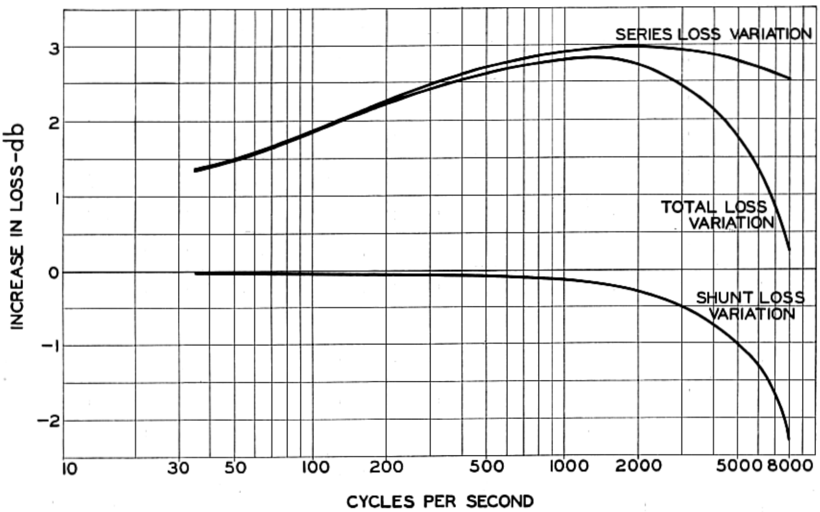

Fig. 6—Attenuation variation of 100 miles of 16-ga. B-22 loaded cable circuit for a temperature change from 55° F. to 109° F.

The method adopted was as follows: Restrict transmission over a particular 16-gauge program transmission pair, as a general proposition, to one direction only. Place the program pairs assigned to transmission in one direction among the 19-gauge quads used for four-wire transmission paths going in the same direction, and the program pairs transmitting in the other direction in the oppositely-bound four-wire group. Fig. 7 shows a cross-section of a typical cable containing six program transmission pairs, three for transmission in each direction.

Loading Coils

The 22-milhenry loading coils used on the program transmission circuit have cores of compressed powered permalloy, which is the magnetic material now generally used in the Bell System loading coils.[4] Their overall dimensions are the same as those of the loading coils for the ordinary telephone circuits in toll cables.

[4] W. J. Shackelton and I. G. Barber, "Compressed Powdered Permalloy—Manufacture and Magnetic Properties," *Transactions, A. I. E. E.*, Vol. 47, No. 2, April, 1928.

Typical effective resistance-frequency curves for the loading coils are given in Fig. 8; these curves include current magnitudes greater than those involved in program transmission service. The core eddy current losses, varying with the square of the frequency, are prin-

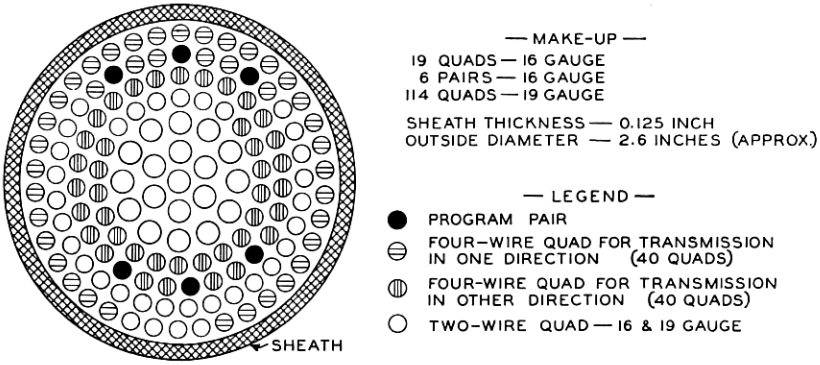

Fig. 7—Cross section of typical full sized cable.

cipally responsible for the resistance increase at the higher frequencies. The increase of attenuation with frequency caused by these core losses is readily corrected, however, by the attenuation equalizers which, as described later, also correct for the attenuation-frequency distortion caused by other factors in the cable circuit.

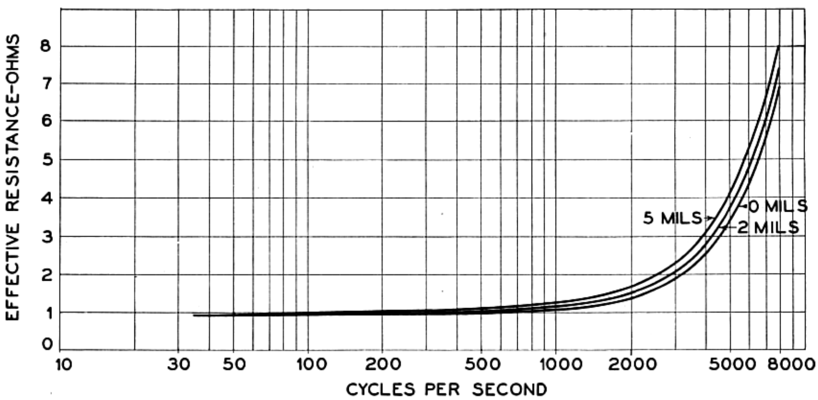

Fig. 8—Effective resistance of 22 milli-henry loading coils used on program transmission circuits in toll cables.

Owing to the low hysteresis loss of the compressed powdered permalloy material, the non-linear distortion introduced by the loading is inappreciable within the range of volumes handled by this program system. For example, in a 1,000-mile circuit for the condition where the power output from each repeater is 1 milliwatt (corresponding roughly to the average power when the program volume is maximum), the non-linear distortion that occurs in the loading causes an increase in the overall transmission loss of the circuit of only 1 db at 8,000 cycles, as compared to the loss for negligibly small power. At 1,000 cycles, the loss increment for the same comparison is .13 db. The

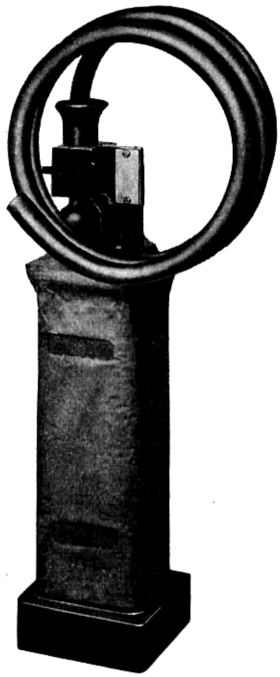

Fig. 9—6-Coil loading case for cable program circuit. $\frac{1}{9}$th actual size.

harmonic production in the coils is another measure of their excellence with respect to non-linear distortion. For a 400-cycle line current of 1 milliampere, the ratio of the third harmonic e.m.f. generated in an individual loading coil to the fundamental e.m.f. is equivalent to a loss of 80 db. The current magnitude above assumed corresponds approximately to the maximum repeater output (single-frequency basis) of 1 milliwatt; the average current that flows in the loading coils is very much smaller due to the smaller average repeater output and to line attenuation. In this connection, it is to be noted that the third harmonic voltage varies with the square of the magnitude of the fundamental current, and directly with frequency. The higher harmonics are, of course, much lower in magnitude than the third harmonic.

For the purpose of minimizing crosstalk, the loading coils are shielded individually by placing each in a metal container. In addition, the leads to the coils in the stub cable and within the coil case are cabled in individually shielded quads, the "IN" and "OUT" leads of a loading coil being in the same shielded quad. As a result of these precautions, the crosstalk between the loading coils is practically negligible. Even at the highest frequencies involved in program transmission, the crosstalk is only of the order of 2 crosstalk units, corresponding to an attenuation of about 114 db.

The shielded program circuit coils required on a given cable are potted separately from the loading coils used on the telephone message circuits. These cases are of welded steel construction. A photograph of a 6-coil case for underground use is shown in Fig. 9. The underground type of case has a special protective coating supplemented by a wrapping of heavy paper.

Amplifiers

Figure 10 is a schematic of the amplifier circuit as used at non-regulating repeater stations. (At regulating stations an automatic transmission adjustment stage is added, which will be described later.) Front and rear views of the amplifier, which is designed for relay-rack mounting in accordance with present-day telephone practice, are shown in Figs. 11 and 12. The lower panel is the amplifier, the upper the transmission adjustment stage, which will be treated later.

In the regular amplifier a standard Western Electric 102-F tube is used in the first stage and a 101-F tube in the second. The amplifier uses resistance coupling and the various coils which affect the transmission performance have very high inductance so as to give the device very uniform transmission performance at different frequencies. The use of permalloy for the cores of these coils makes it possible to obtain the necessary high inductance without going to unreasonable coil dimensions. The gain is controlled by 5 db and 10 db artificial lines in the input circuit with a slide-wire potentiometer for the fine adjustments. Resistances in the grid circuit of the second tube allow an adjustment of the gain at high frequencies. Increasing the resistance causes a decrease in gain at these frequencies. The grid potential of the tubes is obtained from voltage drop in the filament circuit. The condenser in the grid circuit with its associated resistance serves to keep noise which may be present in the filament circuit from entering the grid circuit.

The ideal amplifier should give a constant gain for all frequencies over the band to be transmitted regardless of variations in magnitude

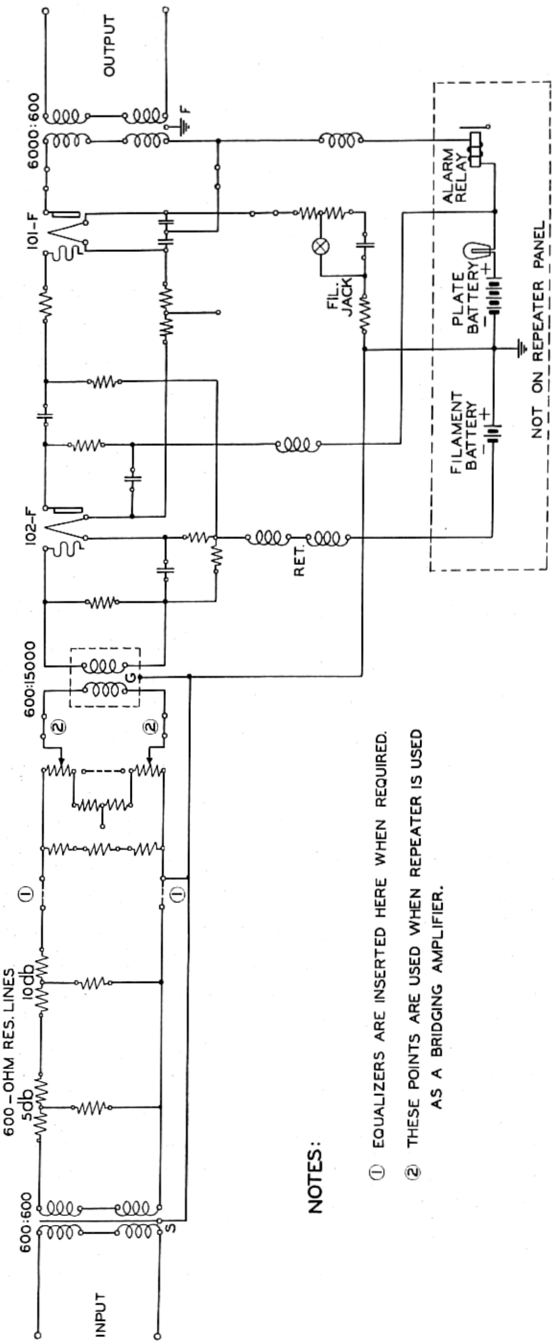

Fig. 10—Schematic of non-regulating repeater for cable program system.

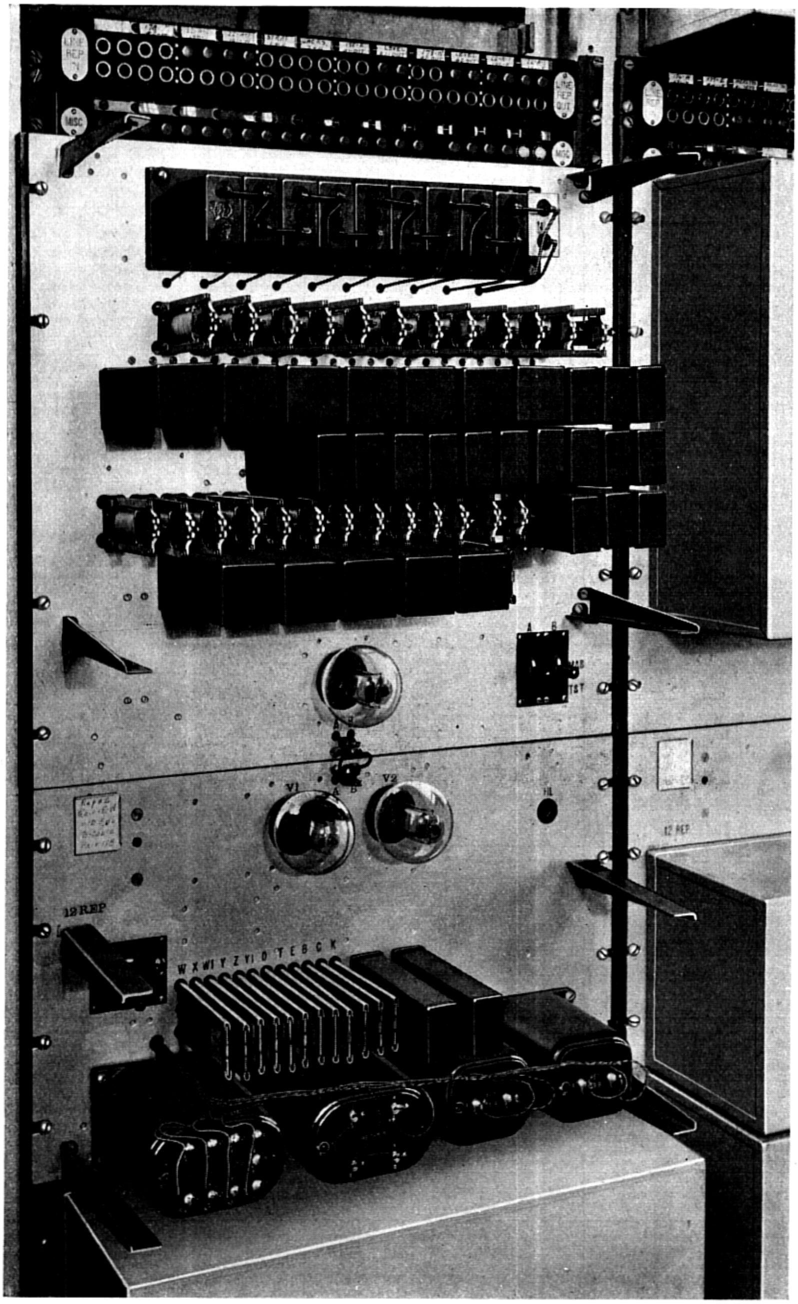

Fig. 11—Front view of program repeater and associated regulating stage.

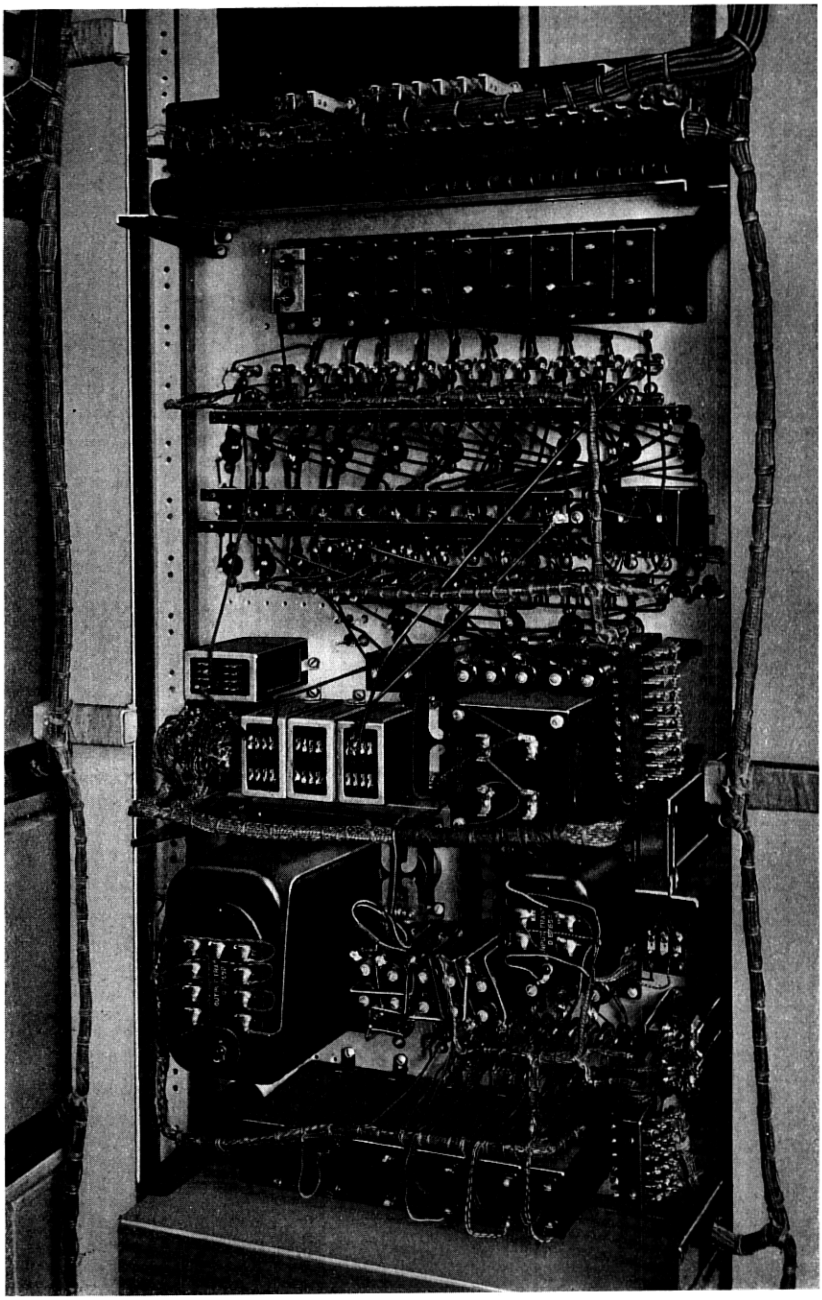

Fig. 12—Rear view of program repeater and associated regulating stage.

of current. No extraneous frequencies should appear in the output and all the frequencies in the band should be transmitted from input to output with equal velocity. With an average spacing of 50 miles for the repeaters, 40 of these are required on a circuit 2,000 miles long so that obtaining proper performance allows only very small departures of the individual repeaters from the ideal characteristics.

With respect to equality of gain at different frequencies, if the top and bottom frequencies of the band transmitted over a 2,000-mile circuit are not to drop more than, say, 2 db, below frequencies in the middle of the band, each amplifier is permitted to be only .05 db down at the edges of the band. (This corresponds to a power difference of 1 per cent.) By the use of resistance coupling and high mutual inductance transformers throughout, the amplifiers developed for this system have been given the characteristics shown in Fig. 13. It will be observed that between 100 and 10,000 cycles the gain differences are less than .05 db while at 35 cycles the gain is only .2 db below the gain at 1,000 cycles.

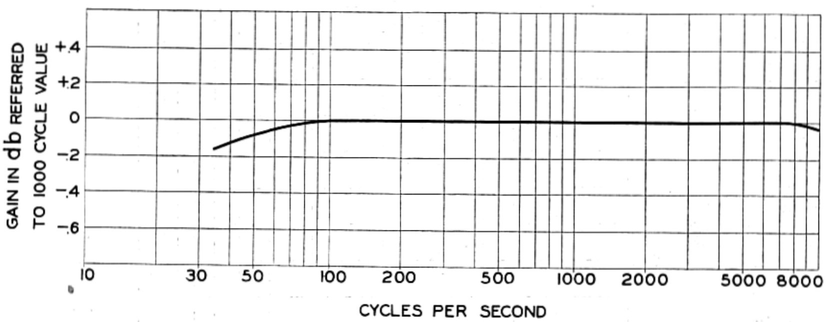

Fig. 13—Gain-frequency characteristic of non-regulating repeater without line equalizer.

With respect to departure of the amplifier from linearity, the effects produced are largely caused by the vacuum tubes. Very little of such distortion is introduced by the amplifier coils. Measurements on one of these amplifiers have shown that with a single frequency output of 1 milliwatt, which is about the average power corresponding to the maximum program volume, the second harmonics are about 50 db weaker than the fundamental, i.e., differ in power from the fundamental in the ratio 1 to 100,000. Other harmonics are lower in magnitude.

Non-linearity in the amplifier also manifests itself by change in gain with current strength. In this amplifier a variation in load from 1 milliwatt to a much weaker load causes a change in gain of only about .01 db, while a variation in load from 60 milliwatts to 6 milliwatts causes a change in gain of about .4 db.

The input and output coils in the amplifier and, in the case of the regulating repeater, the retardation coil also, tend to delay the transmission of low-frequency currents more than those of high frequency; an action which is due to the inductance of these coils shunting the circuit. As this reactance becomes less at the lower frequencies, the delay becomes greater. It can be reduced by increasing the values of shunting inductances. It is largely to reduce this effect that permalloy core coils of extremely high inductance are used, as noted above. The condensers appearing in series also cause delay at low frequencies and must be given capacity sufficiently great to keep the delay within proper limits. Inductance in series or capacity in shunt will also result in delay at the high-frequency end. However, in the frequency range covered by these amplifiers there is no difficulty in keeping this delay small enough to be negligible.

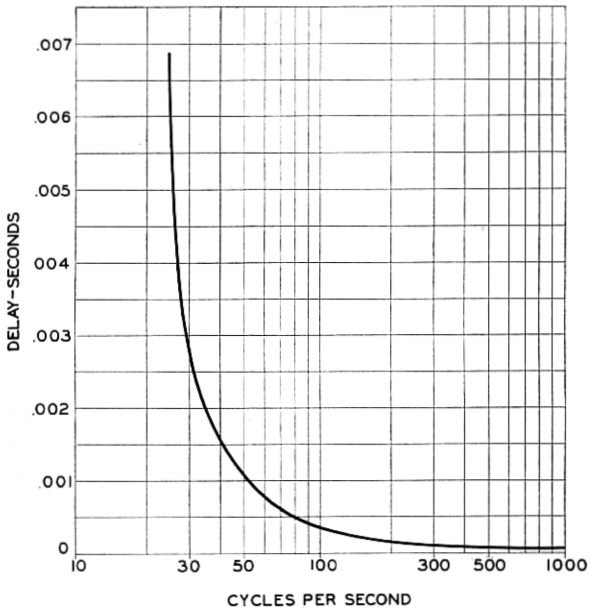

Fig. 14—Delay-frequency characteristic of non-regulating repeater.

The delay characteristic of one of these amplifiers is shown in Fig. 14. With 40 amplifiers in tandem, the overall delay at 35 cycles is 75 milli-seconds greater than at 1,000 cycles, while there is no appreciable difference between the delay at 1,000 cycles and the delay at higher frequencies.

Attenuation Equalizers

As will be observed from Fig. 4, the transmission loss of the cable circuit varies considerably with frequency. Since the amplifier has a flat gain characteristic, an attenuation equalizer is called for to correct the distortion introduced by the cable. A diagram of one of these equalizers is shown in Fig. 15. In Fig. 16 is shown the loss

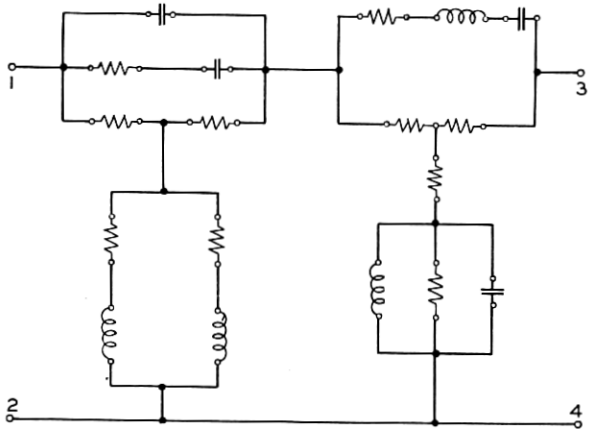

Fig. 15—Schematic circuit of attenuation equalizer.

introduced by a 50-mile section of cable at average temperature, the loss introduced by one of these attenuation equalizers and the total loss of line and equalizer with the offsetting gain introduced by the amplifier.

Automatic Device to Overcome Effects of Varying Temperature Transmission Adjusting

As the temperature of the cable changes its attenuation changes, the amount of the change being different at different frequencies. Referring back to Fig. 6, it is seen that on a cable circuit 1,000 miles long a temperature change from 55° F. to 109° F. causes changes in the transmission as follows:

At 100 cycles 18 db change, power change of 63
At 1,000 cycles 28 db change, power change of 625
At 8,000 cycles 3 db change, power change of 2

When it is appreciated that in an aerial cable a temperature change of 54° F. may take place in only a day or two, the importance of compensating for this effect may be appreciated.

In order to compensate for this effect of varying temperature, a regulating stage is added to the amplifiers at the various regulator stations. Fig. 17 shows how the regulating network stage is added to one of the amplifiers and also shows the general nature of the regulating network circuit. Because of the peculiar and complicated way the transmission loss of the cable circuit varies with temperature,

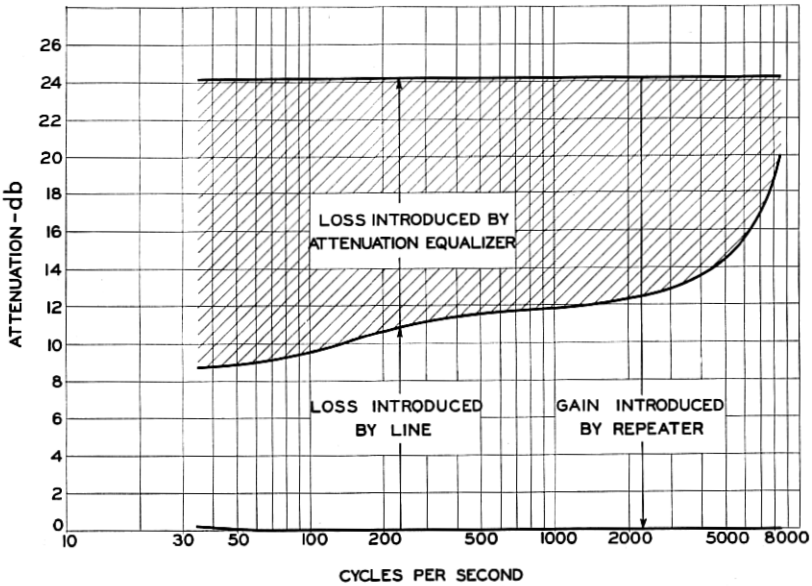

Fig. 16—Attenuation-frequency characteristic of line equalizer and 50 miles of 16-ga. B-22 cable circuits.

a somewhat complicated regulating network is called for. Front and rear views of one of these regulating networks are shown in Figs. 11 and 12, the upper panel being the regulating network and the lower the normal amplifier. Fig. 18 shows how the gain characteristic of the amplifier is altered by different steps of the regulating network. This is very closely complementary to the change in cable loss caused by the temperature variations and thus it will be evident that the effects of the temperature changes are largely eliminated.

Delay Equalizers

The velocity of transmission through a loaded cable decreases as the frequency is increased toward the cutoff point of the loading. To neutralize this effect, delay-equalizing networks are inserted in the circuit which retard the lower frequencies, thus equalizing the velocity

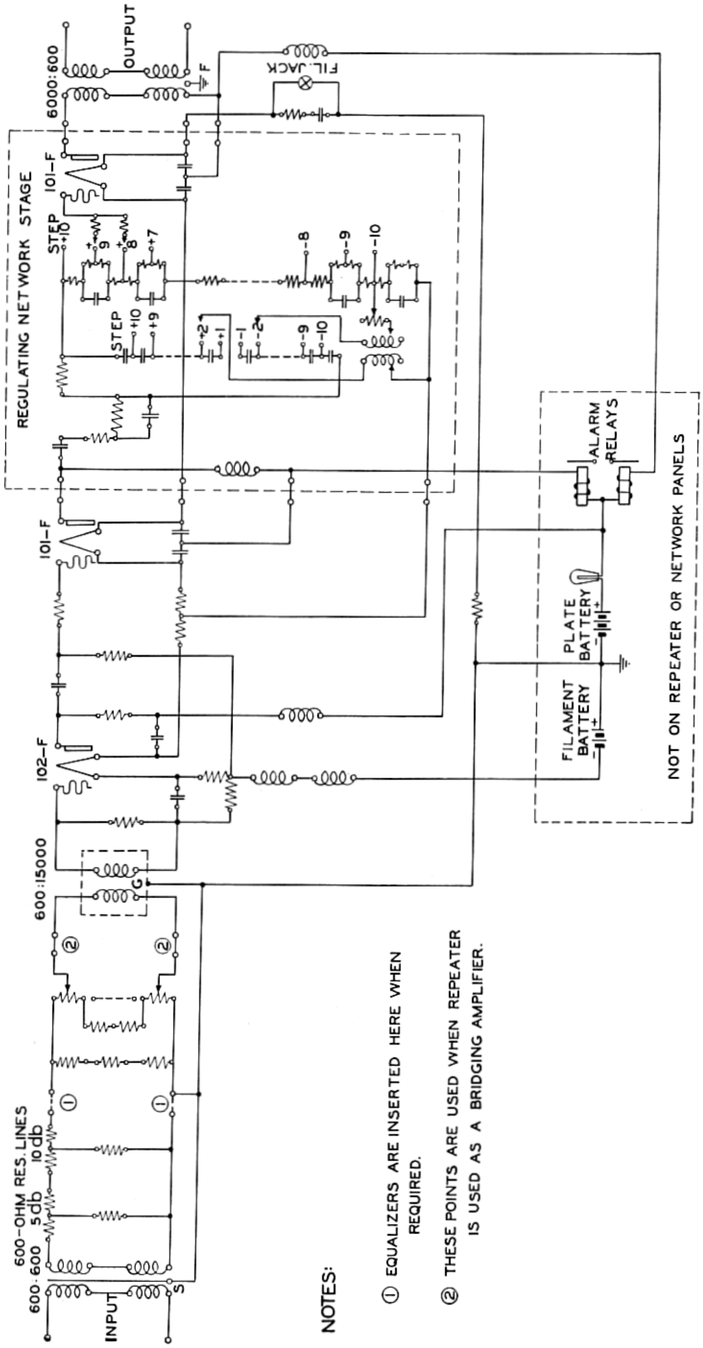

Fig. 17—Schematic of regulating repeater for cable program system.

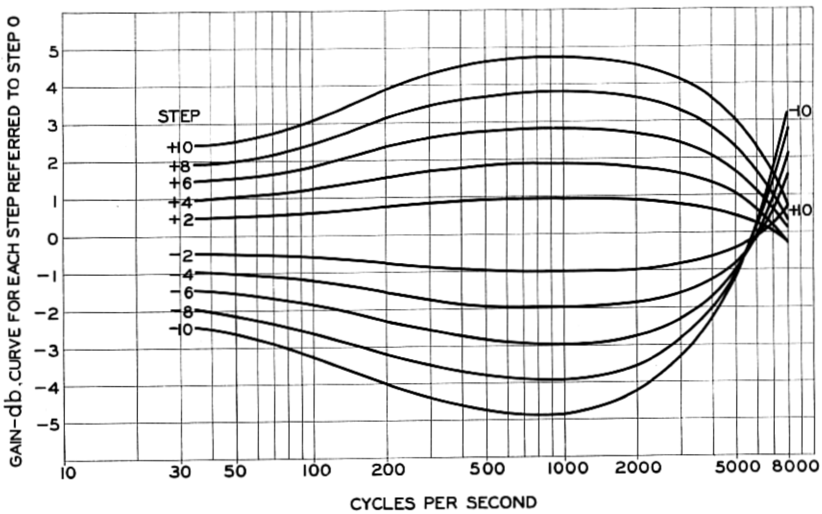

Fig. 18—Gain-frequency characteristic of regulating repeater without line equalizer.

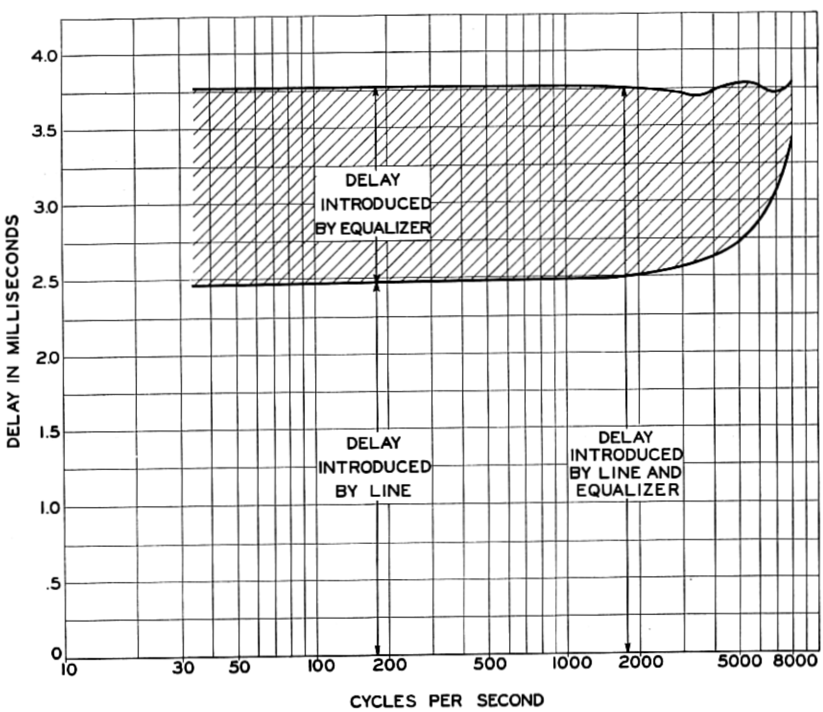

Fig. 19—Delay-frequency characteristic of 50 miles 16-ga. B-22 cable with and without delay equalizer.

of transmission through the combination of cable and networks for all frequencies in the band to be transmitted. Fig. 19 shows the delay characteristic of a section of cable 50 miles in length, with and without the delay-equalizing networks. The delay is seen to be maintained within ± 0.05 milli-second of a constant value. A schematic circuit of these networks is shown in Fig. 20. With the greatest

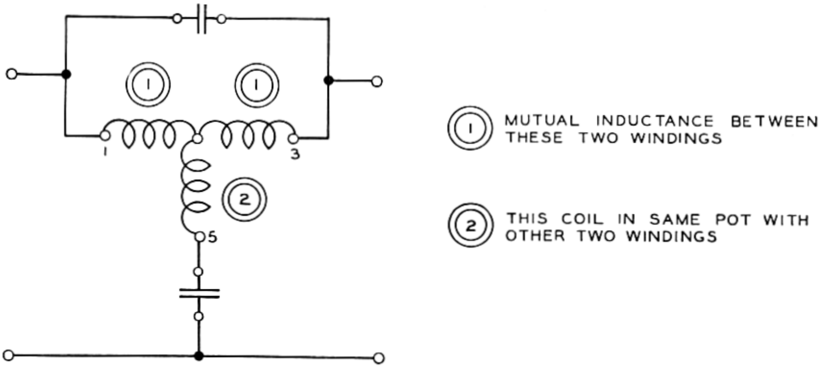

Fig. 20—Schematic circuit of section of delay equalizer. For a 50-mile equalizer, three kinds of sections are used which vary in the resonant frequency and in the sharpness of resonance. The first three sections are of one kind, the fourth is of another and the last seven are of the third kind.

length of cable circuits which will be used in this country for program transmission, this amount of deviation per section is not sufficient to cause objectionable distortion. For a 50-mile section uncorrected, the delay at 8,000 cycles would be 0.9 milli-second greater than at 1,000. A description of these delay-equalizing networks with the theory of their performance is being presented in another paper so that a more detailed description is omitted in this paper.

Office Wiring

Owing to the wide frequency range transmitted over the circuit, special care must be taken with the office wiring. This is to avoid excessive variations in the losses introduced by this wiring due to changing humidity conditions. A new type of insulated cable is used in which the textile material of the insulating wires has been very thoroughly washed to remove all traces of foreign substances, so that the absorption of moisture with its accompanying increase in loss is greatly reduced.[5] The office cabling is also shortened as much as possible, the outside cable connecting directly to the repeaters without

[5] H. H. Glenn and E. B. Wood, "Purified Textile Insulation for Telephone Central Office Wiring," *A. I. E. E. Transactions*, Vol. 48, April, 1929.

passing through the usual test board. At points in the circuit sensitive to noise interference or crosstalk where the energy level of the transmitted signals is very low, the circuit units are connected by means of shielded pairs. This shield is connected to filament ground, as are also the cases of the various transformers which are insulated from the supporting metallic frame. The unavoidable noise potential existing between the frame and the filament circuit cannot then produce any appreciable disturbance in the circuit.

Overall Performance of System

A measurement of the transmission loss of the 2,200-mile test length of B-22-N cable circuit gave results as indicated in Fig. 21.

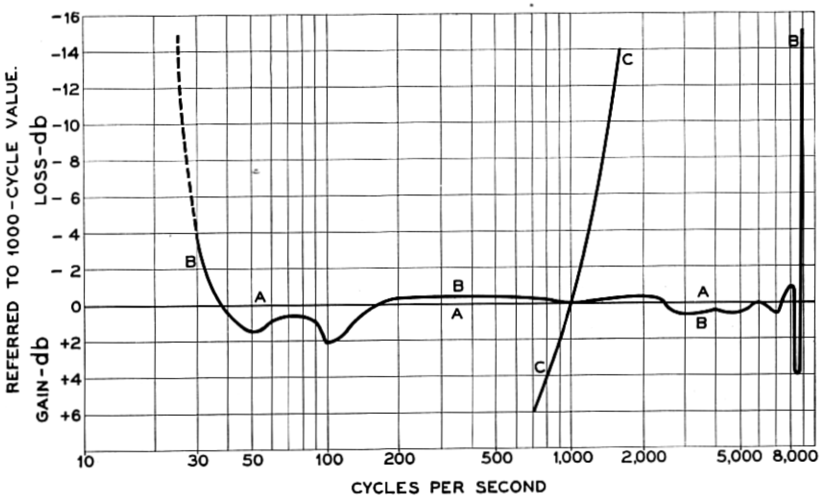

Fig. 21—Transmission-frequency characteristics of 2,200 miles of 16-ga. B-22 cable program transmission circuit. Curve A—Ideal characteristic. Curve B—Measured characteristic. Curve C—Line without equalizers.

It will be observed that over the range from 35 cycles to 8,000 cycles the transmission loss was practically the same at all frequencies, departing only about ± 2 db. For comparison, another curve (*C*) is given on the same drawing showing the transmission characteristic which would have been obtained if distortionless amplification had simply been added to the line with no attenuation equalizers.

The delay-frequency characteristics of the 2,200-mile test length of B-22 circuit are shown in Fig. 22. Two curves are given, one for the circuit without delay equalizers, the other with delay equalizers.

With respect to non-linear distortion, it was found by test that when the maximum volume was held at about − 5 db, as read on a volume indicator, or about 1 milliwatt of average power, the non-linear distortion became inappreciable. As a matter of fact, occasional bursts up to at least 0 db were not badly distorted. It may be observed that the − 5 db volume is about 10 db less than repeaters

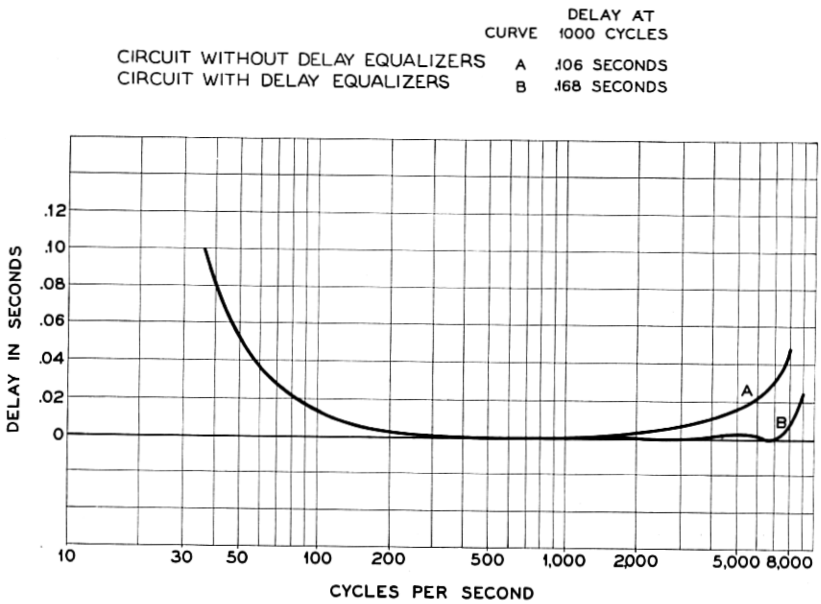

Fig. 22—Delay characteristics of 2,200 miles of 16-ga. B-22 cable program transmission circuit.

of the same nominal capacity and loading coils of similar characteristics handle without appreciable distortion under regular message telephone circuit conditions.

The minimum volume which could be transmitted over the cable circuit, which was set by noise and crosstalk picked up by the program circuit, was found to be about − 50 db at the repeater outputs. This means that the volume range carrying capacity of the circuit was about 45 db, just a little more than the figure 40 db which was previously mentioned as a reasonable standard for present-day conditions of broadcasting. If short bursts of music are allowed to go up to the zero volume at the repeater outputs, the system can evidently handle about 50 db volume range.

Using special pickup apparatus and loudspeakers capable of handling practically the whole audible frequency range, tests have been made over the 2,200-mile looped-back circuit in which comparison was made of the transmission with and without the cable included. When an

8,000-cycle low-pass filter was included under both conditions it was found that listeners had considerable difficulty in consistently picking a difference. In fact, the ordinary observer could not be relied upon to pick differences consistently even when the 8,000-cycle filter was not included.

Conclusion

This development was undertaken to provide a system for obtaining satisfactory channels for the transmission of broadcast programs in the rapidly growing cable network of the Bell Telephone System. The time required to complete such a development and the need for advance planning in the cable plant made it essential that the channels be adequate to render service for a number of years. Improvements in broadcast reproduction may be expected to continue and may very well result in changes in the present frequency allocations to give space for wider bands. The cable system described in this paper was, therefore, developed to possess transmission characteristics superior to present-day radio systems, the margin anticipating improvements which may take place in the future.

Acknowledgment

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