A Carrier Telephone System for Toll Cables *

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A new 12-channel carrier telephone system for existing cables is described. This system, which incorporates a number of interesting departures from the previous carrier art, is now being manufactured in considerable quantities to meet increased traffic requirements.

AN important advance in the art of carrier telephony has been made by the development of a new 12-channel system, known as the type K, for toll telephone cables of existing type. It is applicable both to cables installed underground, and also to aerial cables, for which the wide range of temperature variation introduces quite difficult transmission problems. Field trials on cables previously installed between Toledo and South Bend have been successful, and the system is now being manufactured to meet field demands.

This new development is an outgrowth of the experiments at Morristown, New Jersey, described by Messrs. Clark and Kendall before the American Institute of Electrical Engineers in 1933,[1] and the essential principles of the new system were included in those experiments. The earlier work dealt, however, with cable specially designed for carrier operation, and only underground cable was experimented with. As that work drew to a close, it became clear that because of general economic conditions several years would elapse before the Bell System would require any substantial increase in toll facilities. Hence this early system was not put into commercial form, but work was continued to determine the extent to which carrier could be applied to existing cables, of which more than 15,000 miles were available for such use. Serious problems of cross-talk at high frequencies had to be reckoned with. A more serious problem, however, was that of maintaining stability of transmission, since with aerial cable, which comprises about two-thirds of the existing cable mileage, the total variation in attenuation, due to temperature variation, is about three times that for underground cable, and the rate of variation not infrequently is several hundred times as great.

In spite of these and other difficulties, the capabilities of the present system go far beyond those of previous systems. As a develop-

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[1] For references see end of paper.

ment objective the maximum length was taken as 4000 miles, with as many as five separate systems linked together. On the basis of results thus far obtained it is expected that for these exacting conditions the performance with respect to crosstalk, noise, transmission stability, width of voice band and other characteristics will equal or exceed that of previous facilities for much shorter distances.

Superior performance has been achieved without material effect on the cost of the system. For distances of a few hundred miles, on moderately heavy traffic routes, it will provide telephone circuits at a much lower cost than previous facilities. The minimum distance for which the system will be useful may be less than 100 miles.

Interesting features of the new system are:

(1) A line of very high attenuation, requiring high-gain repeaters spaced at approximately 17-mile intervals. This would mean, for the maximum distance for which the system is designed, more than 200 repeaters in tandem.

(2) The use in the repeaters of the negative feedback principle of amplification to obtain the requisite stability and freedom from modulation.

(3) Small auxiliary repeater stations, established between existing voice-frequency repeater stations, housing equipment which can be left for considerable periods of time without attention.

(4) A system of transmission regulation whereby huge variations of attenuation, differing at each frequency, are automatically equalized to a high degree of accuracy.

(5) New methods of crosstalk and noise reduction. Small adjustable mutual inductance coils are connected between carrier pairs to balance out the crosstalk. The noise is kept at an extremely low level to permit the high gains.

(6) Channel terminal equipment designed so that it may be used in other types of carrier systems, thus simplifying development and manufacture, and facilitating the interconnection of different types of systems.

(7) Speech bands considerably wider than those of existing facilities. The increase is obtained by spacing the channels at uniform 4000-cycle intervals, and employing channel band filters containing quartz crystal elements.

(8) High-speed transmission, which is of considerable value from the standpoint of minimizing delays and echoes.

A general description of the system is presented herein, and the different parts are taken up in greater detail in other papers.

General Considerations

The type K system, the elements of which are illustrated schematically in Fig. 1, operates on a "four-wire" basis, using the same frequency range, but different electrical paths, for opposite directions of transmission. Thus it differs from open-wire carrier systems, for which the line is not suitable for four-wire operation, and which therefore require complicated and expensive filters to separate the different frequency bands used for transmission in opposite directions. A high degree of shielding between the two cable paths is necessary to avoid the effects of near-end crosstalk, which would be serious because of the large level differences existing at the repeaters and the terminals. On routes where two or more cables exist, such shielding is obtained by employing two separate cables, with transmission in one direction only, in each section of cable. On single-cable routes, a similar arrangement is obtained by adding a small cable. Where there is no cable, two small cables may be provided. Also, satisfactory shielding between the carrier pairs used for opposite directions of transmission has been obtained in short experimental lengths of cable by the use of a layer shield.

Frequency Allocation

In contrast to the original Morristown system, which gave nine one-way channels per pair in the range from 4 to 40 kilocycles, the type K system has twelve channels in the range from 12 to 60 kilocycles. As shown in Fig. 2, the frequency range of the type K system is roughly double that of preceding open-wire carrier systems.[2] The choice of 12 and 60 kilocycles as the lower and upper frequency limits was governed by economic considerations, and there is nothing technically insurmountable either in going to considerably higher frequencies or in utilizing the lower frequency range, which is now idle except for the use of the d-c. path for purposes of transmission regulation and fault location. Important factors influencing the selection of the upper frequency are the crosstalk, which depends on the number of pairs utilized for carrier in one cable and the extent to which special crosstalk balancing means are used, and the attenuation, which largely controls the spacing between repeaters. Factors affecting the lower limit include the difficulty of maintaining accurate transmission regulation over the whole frequency range, and the design of the repeater, which becomes harder as the ratio of maximum to minimum transmitted frequency is increased.

The frequency range between 12 and 60 kilocycles accommodates 12 speech channels, each occupying a gross band of 4 kilocycles. The

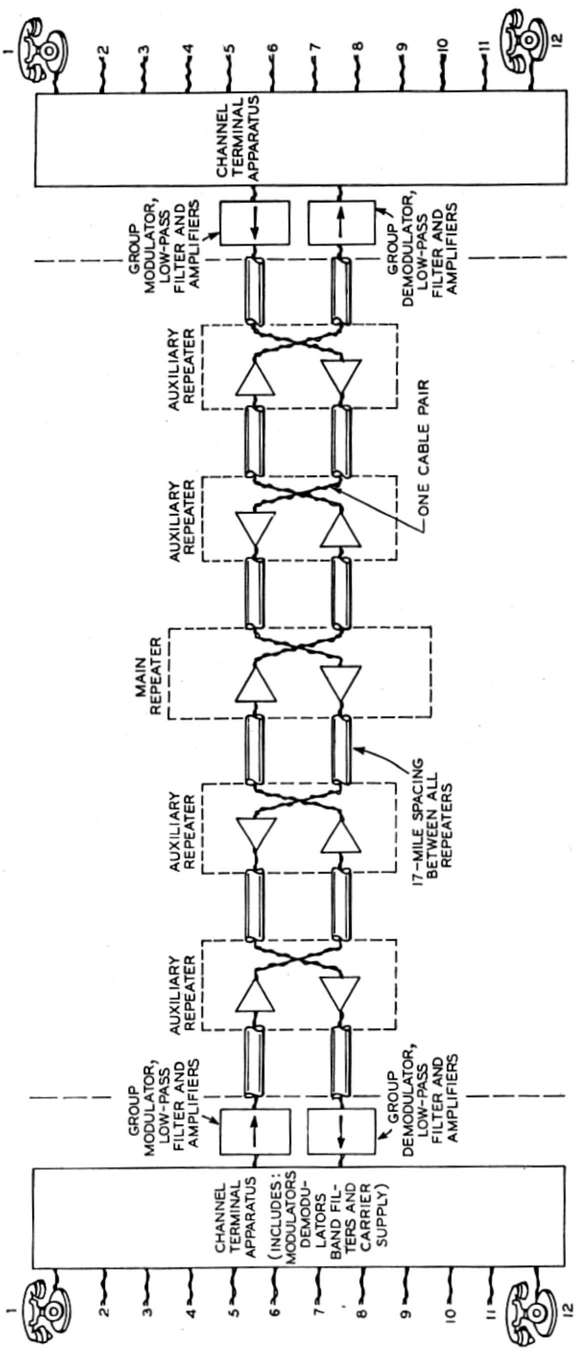

Fig. 1—Schematic of Type K system.

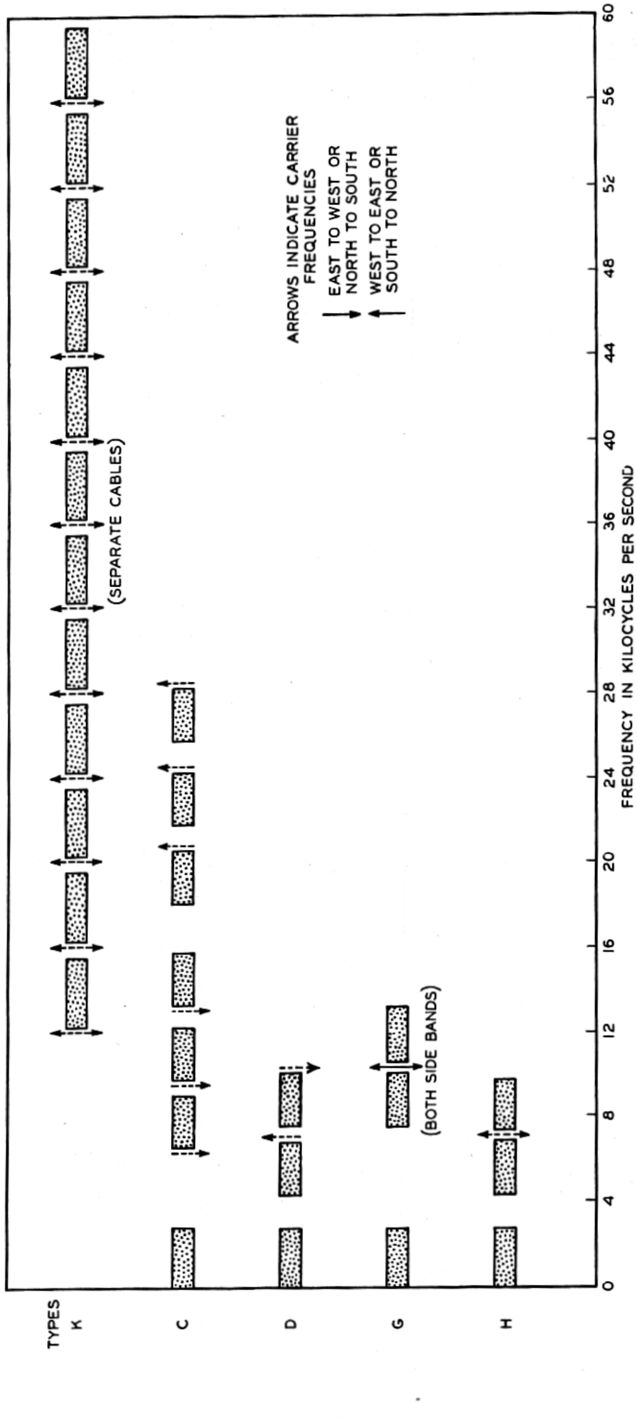

Fig. 2—Frequency allocation of carrier telephone systems.

single sideband method of transmission is employed, with carrier frequencies suppressed. The choice of a group comprising 12 channels was influenced not alone by the requirements of the type K system itself but also by those of other broad-band systems. From the earliest stages of the broad-band development it was recognized that there would be considerable advantage from the standpoints of flexibility of interconnection, of minimum development effort, and of large scale production of equipment units, if the designs of different broad-band systems could be so coordinated as to enable the same design of channel terminal equipment to be employed for each. A common 12-channel terminal unit developed for this purpose is used in the type K system.

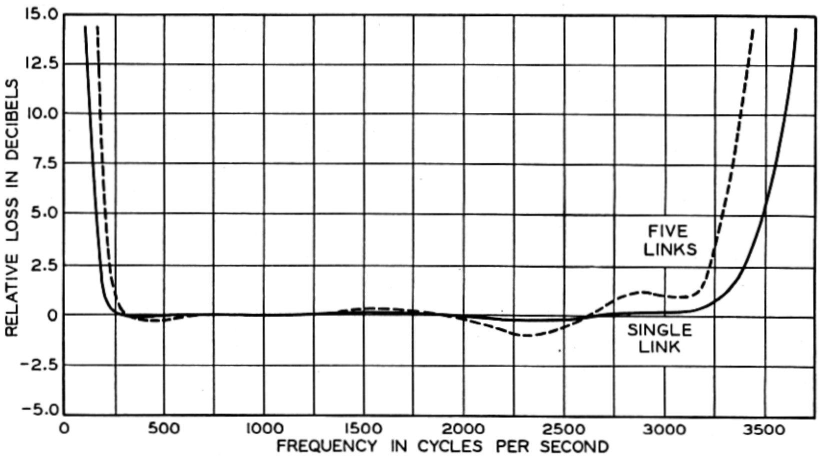

Fig. 3—Transmission frequency characteristics of overall circuit.

The spacing of the channels in broad-band systems is important from the standpoint of the channel selecting circuits and the width of the derived voice circuit. As discussed in a recent article, a uniform 4000-cycle interval has been adopted for the different channels of all broad-band systems.[3] The speech band width obtained with this spacing is in keeping with recent improvements in telephone instruments and other parts of the telephone plant. Overall transmission-frequency characteristics for a single link and a five-link connection are shown in Fig. 3.

Cable Attenuation

The type K system is designed to be applied to the No. 19 AWG (0.9 mm.) pairs commonly found in existing cables. (The Morristown system used 16-gauge pairs.) Because the conductors are small and closely spaced, with paper and air dielectric, the attenuation of a non-loaded 19-gauge pair at the frequencies involved is inherently high, as will be seen from Fig. 4. Because of the high attenuation, the repeaters must be placed much closer together than is necessary for voice-frequency cable circuits. Fortunately this effect is partly offset by the fact that it is possible, as discussed later, to use higher gains in the carrier repeaters.

The cable pairs exhibit the rise in attenuation with frequency which is familiar in most transmission circuits. This effect is brought about largely by the increase in conductor resistance, due to skin effect, and

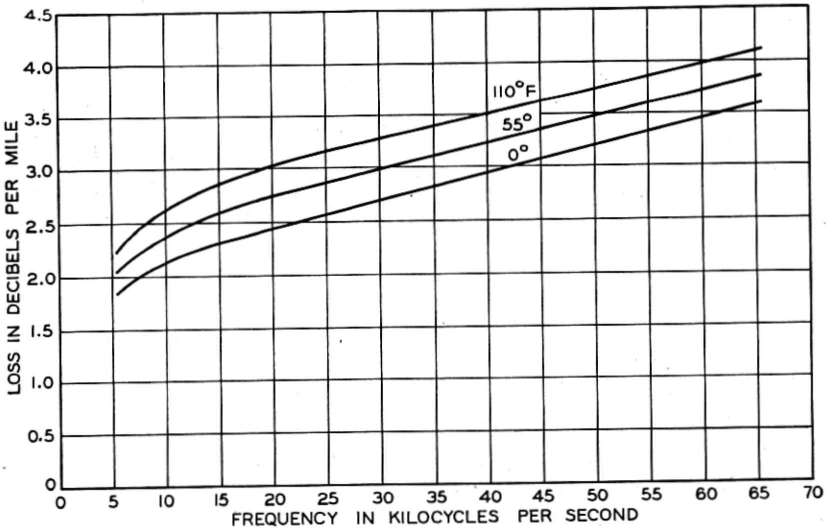

Fig. 4—Attenuation of 19-gauge non-loaded cable pair.

the increasing dielectric losses. More important than this, however, is the fact that the resistance of the wires and the other "constants" of the cable pair undergo variations with temperature, which in turn affect the attenuation. The magnitude of the result for a representative non-loaded 19-gauge cable pair is illustrated by the curves of Fig. 4, which show, respectively, the attenuation for an average temperature, assumed to be 55° F., and for 0° F. and 110° F. The latter values, often taken as the extremes of annual variation for an aerial cable, are in fact frequently exceeded. One reason for this is that when the sun is shining directly on an aerial cable, it may assume a temperature from 15° to 25° above that of the ambient air. The range of temperature variation (and attenuation variation) for an aerial cable may be half as much in one day as in an entire year. For an underground cable, changes of temperature occur quite gradually and the total annual variation is about one-third of that for an aerial cable.

These relations between the attenuation of a cable pair and the frequency and temperature are of fundamental importance in the design of the type K system. First of all, since the attenuation at 60 kilocycles is about 4 db per mile, the total attenuation for a cable circuit of the length used in designing the type K system, i.e., 4000 miles, would be approximately 16,000 db. This must be offset by a corresponding gain.

In the next place, differences in the attenuation at the different frequencies would, if uncorrected, become so great that signals of the less attenuated channels would overload the repeaters, while those of the more attenuated channels would drop down into the noise region. Hence, each repeater must be given a gain-frequency slope which is complementary to the attenuation slope of the line.

Finally, the changes of transmission due to temperature variations and other causes must be compensated so precisely that the net variation in each channel is held within very narrow limits. The method of doing this is explained later. Here it is interesting merely to consider the magnitude of the problem. For the top channel, assuming a 4000-mile circuit, the annual variation in attenuation of an aerial cable pair might be approximately 2000 db. The systems thus far installed have, of course, been limited to much shorter distances than this.

Even if the change of attenuation with temperatures were related to frequency by a simple law, correct compensation over the frequency range would be far from easy. To a casual inspection the differential between any two curves of Fig. 4, for example those for 55° F., and 110° F., will not appear serious. This differential, which becomes very large for a long circuit, is a complicated function of the frequency.

The attenuation differential with temperature can be considered as made up of two components, one which is independent of frequency and another which varies with frequency. The former component, which is much the larger, requires a gain adjustment which is uniform or flat over the frequency range of the system. The latter component is frequently referred to as the "twist." For the range from 12 to 60 kilocycles, the maximum change of attenuation with temperature occurs near 28 kilocycles. Hence this frequency has been used as a datum point in determining the twist. The shape of the twist component is apparent from Fig. 5, which shows the net loss per mile at temperatures of 0° F., and 110° F., assuming that the attenuation has been equalized so as to obtain a flat characteristic at 55° F., and that the gain is then adjusted so as to hold the transmission constant at 28 kilocycles as the temperature varies. Although the twist is small enough so that it need not be corrected at each repeater, it is too large to be allowed to accumulate over a very long distance.

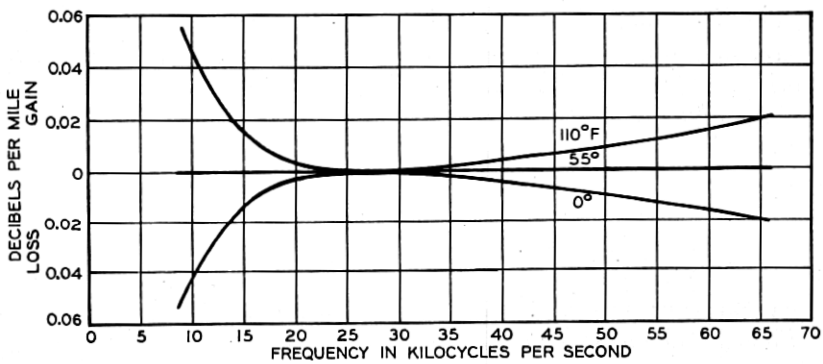

Fig. 5—Twist characteristics of 19-gauge non-loaded cable pair.

Crosstalk

As noted above, crosstalk between opposite directions of transmission is avoided by using two separate cables (or shielded compartments in the same cable). To prevent crosstalk in offices, special measures are employed. There remains the problem of "far-end" crosstalk between pairs in the same cable which transmit in the same direction. The pairs are packed closely together, and substantial crosstalk occurs between them because of small departures from symmetry and slight imperfections of twisting. However, by abandoning the use of phantoms and by connecting small adjustable mutual inductance coils between each carrier pair and every other carrier pair, sufficient crosstalk reduction is obtained to permit transmission up to 60 kilocycles on a substantial number of pairs.[4] The scheme is illustrated in Fig. 6.

In the original Morristown cable, the crosstalk was reduced in part by separating the 16-gauge carrier pairs from one another by 19-gauge quads which served as spacers. With existing cables, however, the use of spacers would be impracticable since this would require resplicing the cable at every joint, and therefore reliance must be placed largely on balancing. Since the number of combinations to be balanced increases approximately as the square of the number of pairs employed for carrier, the number of balancing coils required for even a moderate complement of carrier pairs becomes quite large. With 40 carrier pairs, for example, the number of coils required is 780. The balancing coils are mounted on panels as shown in Fig. 7 and are connected together in a crisscross arrangement. Each repeater section is balanced separately, the balancing panels being located in the repeater station.

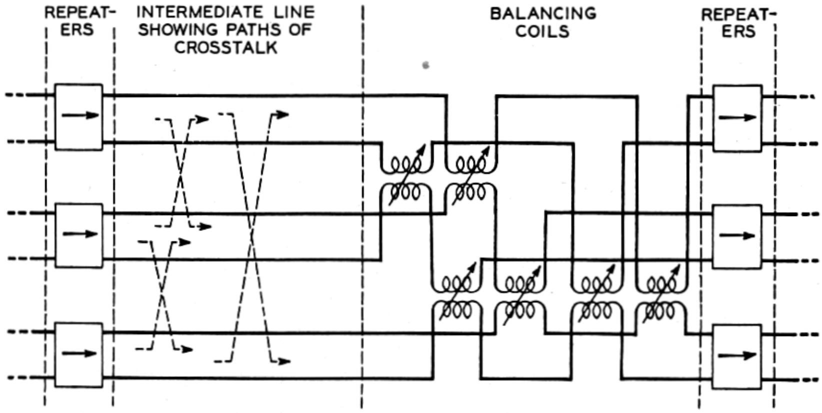

Fig. 6—Method of balancing out crosstalk.

Other measures are necessary to supplement this balancing technique. To reduce the crosstalk coupling, and also to average the transmission characteristics of different pairs, the carrier pairs in different quads of an existing cable are respliced about every mile so as to approach random splicing. The crosstalk coupling between the two sides of a quad is reduced by test splicing at the middle of a repeater section and the quads are split at repeater points. In a new cable, of course, the desired splicing arrangements are introduced at the time of installation. The carrier pairs are also transposed from one cable to the other as indicated in Fig. 1. This avoids interaction crosstalk that would take place, through the medium of the voice-frequency pairs, between the high-level carrier outputs on one side of a repeater station and the low-level inputs on the other side. There is of course, a similar effect between carrier pairs at any point in a repeater section. This is much less serious since no level difference is involved, but it does tend to limit the effectiveness of the balancing over a range of frequencies.

Reflections resulting from impedance irregularities reverse the direction of propagation and therefore produce far-end crosstalk from near-end crosstalk. This crosstalk cannot readily be balanced out over a range of frequencies. To avoid it, it is necessary that the impedances of successive lengths of cable pair be substantially uniform and also that the impedance of the equipment be closely matched to the characteristic impedance of the cable pair.

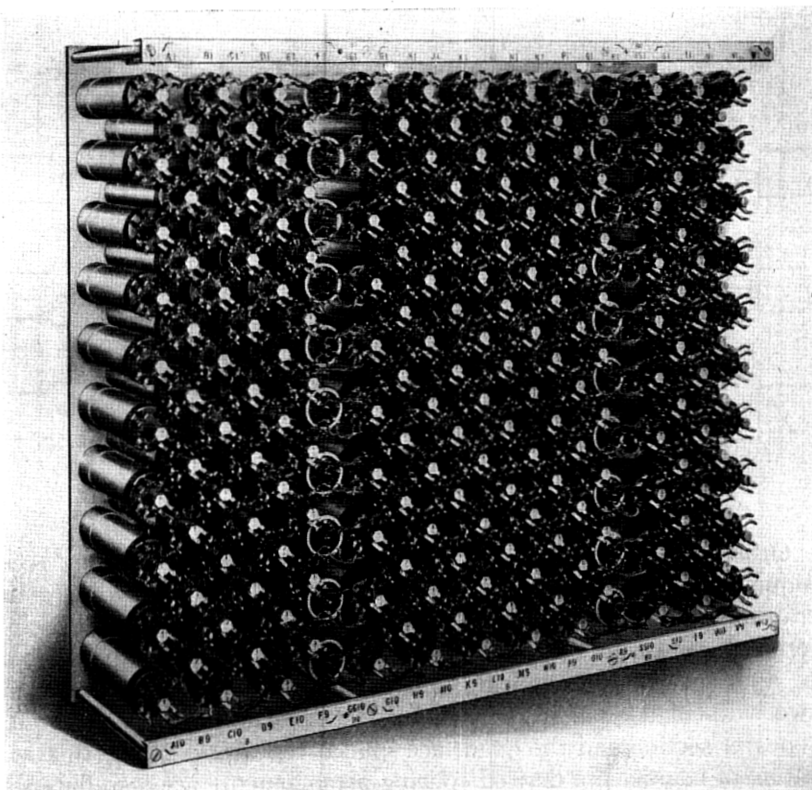

Fig. 7—Crosstalk balancing panel.

Noise

The cable pairs are fairly well protected by the lead sheath from external electrical disturbances. However, high-frequency noise originating in the voice-frequency repeater stations due to relay operation, etc., would, unless prevented, enter the cable over the voice-frequency pairs and thence would be induced in the carrier pairs. Such noise would be excessive at the low-level carrier inputs. It is avoided by connecting, in each voice-frequency pair in the "low level" cable on each side of a voice-frequency repeater station, a coil which suppresses longitudinal noise currents. Similarly, it is necessary to keep high-frequency noise from entering the cable where open-wire pairs tap into it and frequently also where branch cables are connected. For this purpose simple noise suppression filters are employed. With these and other measures the noise on the carrier pairs can, at the highest frequencies where the amplification is greatest, be brought within a few db of the basic noise due to thermal agitation of electricity in the conductors themselves.

Velocity of Transmission

Voice waves travel through loaded cable circuits at from 10,000 to 20,000 miles per second, the higher speed being used for the longer circuits. On very long connections, even if echo suppressors are employed this velocity results in transmission delays which introduce difficulties in conversation.[5] The use of non-loaded conductors for the type K systems results in an overall velocity of transmission of about 100,000 miles per second, a speed so high that such difficulties are greatly reduced and satisfactory telephone conversations are possible over the longest distances for which connections may be required.

Repeaters

Since the noise level in the cable circuits can be made quite low, the carrier currents may be permitted to drop to levels below those used on voice-frequency circuits or on open-wire carrier circuits, and the repeaters may have higher gains. In the cable carrier system, the noise has been so reduced that the level of the top channel at the repeater input may on the average be dropped about 60 db below the voice level at the transmitting switchboard. The amplifier gains at the top frequency range from about 50 to 75 db, and the output level of each of the 12 channels is about 10 db above that at the switchboard. The average repeater spacing is about 17 miles.

The tube which was developed for the gain stage of the amplifier is a pentode with indirect heater. The heater requires a potential of 10 volts and a current of 0.32 ampere and the plate 150 volts. The tube in the power stage is similar in type but requires a heater current of 0.64 ampere at 10 volts. With this power tube a feedback of about 40 db has been found to provide a satisfactory reduction of interchannel modulation.[6] Both tubes were designed to have long life with very reliable performance.

Description of Amplifier

Each repeater comprises two amplifiers of the type illustrated in Fig. 8. A schematic diagram of the amplifier circuit is shown in

Fig. 9. Three stages with impedance coupling are used and the feedback circuit is connected between the plate circuit of the last tube and the grid circuit of the first. The amount of gain and the slope of the gain-frequency characteristic are controlled by the condensers and line equalizer in the feedback circuit.

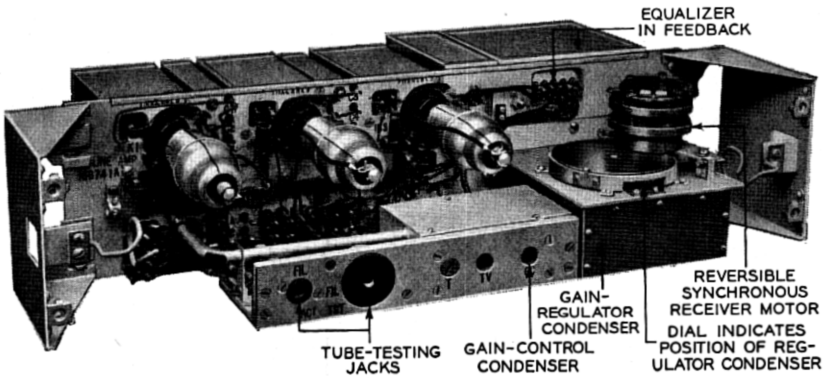

Fig. 8—Line amplifier.

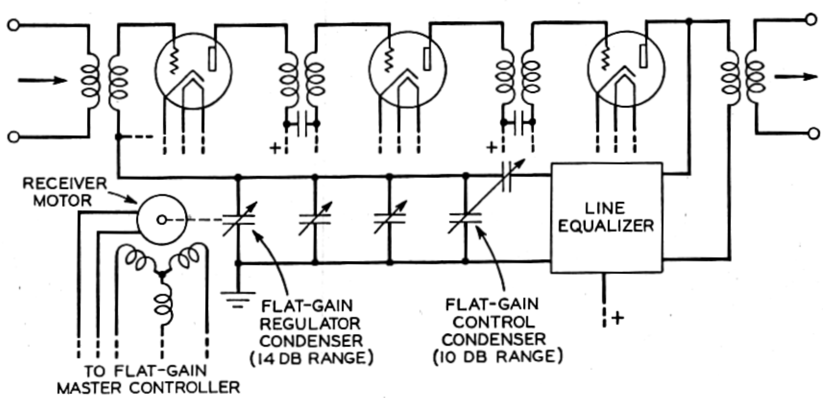

Fig. 9—Schematic of line amplifier.

The line equalizer has the same attenuation slope as the line. In the introduction of this equalizer in the feedback circuit careful attention to phase shift requirements was required. Four types of equalizers are available, for different repeater spacings, to compensate for the cable distortion which occurs at a temperature of 55° F., additional means being provided to compensate for variations which occur as the cable temperature swings away from this value. The solid curve of Fig. 10 shows a repeater gain characteristic with one of these equalizers in the feedback circuit.

The correction introduced by the line equalizers is subject to errors which, although small at each repeater point, become important for a moderate length of system. Supplementary equalizers have been designed to correct for these. Two types of deviation are considered,

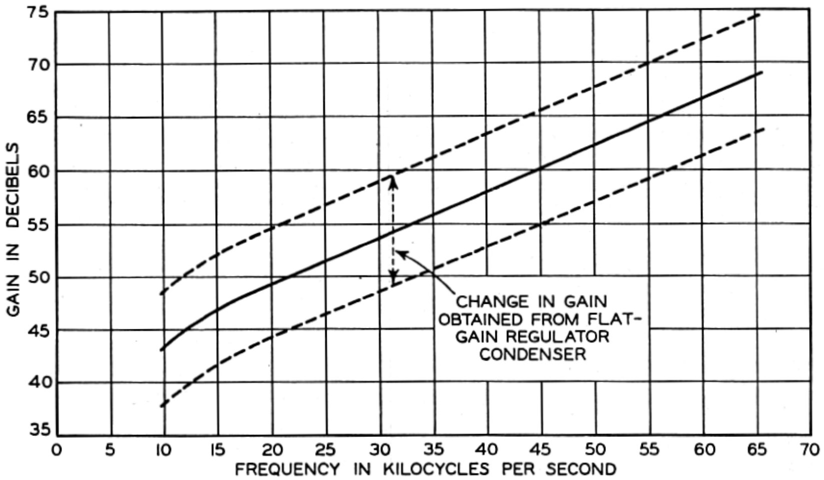

Fig. 10—Amplifier gain characteristics.

that of the cable and that of the amplifier. As the characteristics of cables manufactured at different times show slight departures from one another, two shapes are required to correct their deviations. There is one correction for concave deviations and another for convex.

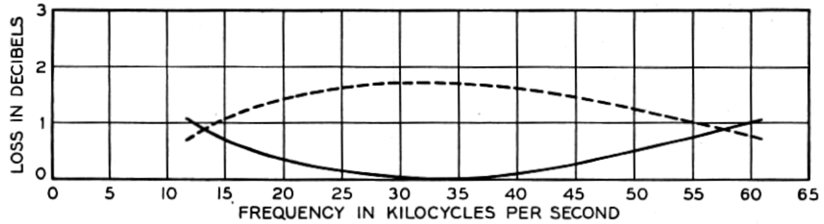

Fig. 11—Characteristics of cable deviation equalizers.

The amplifier requires but one type of correction. The characteristics of these equalizers are shown in Figs. 11 and 12. The equalizers for amplifier deviations are used about every 10th repeater and those for the cable deviations, at distances of 300 to 400 miles. At normal temperature (55° F.), the correction applied by these networks will, for a 500-mile system, result in a frequency characteristic which is flat to within less than 2 db over the range from 12 to 60 kilocycles. For a longer circuit further corrective measures will be provided.

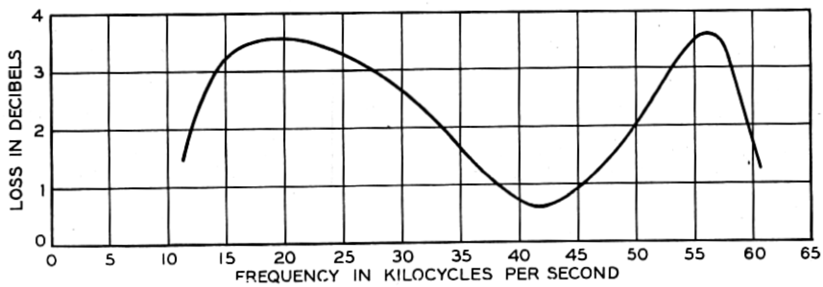

Fig. 12—Characteristics of amplifier deviation equalizer.

Regulation for Temperature Effects.

The method adopted for controlling the repeater gain to compensate for temperature changes is similar to that which has been found satisfactory for voice-frequency cable circuits. This is the pilot wire method in which a pair of cable conductors extending over the section

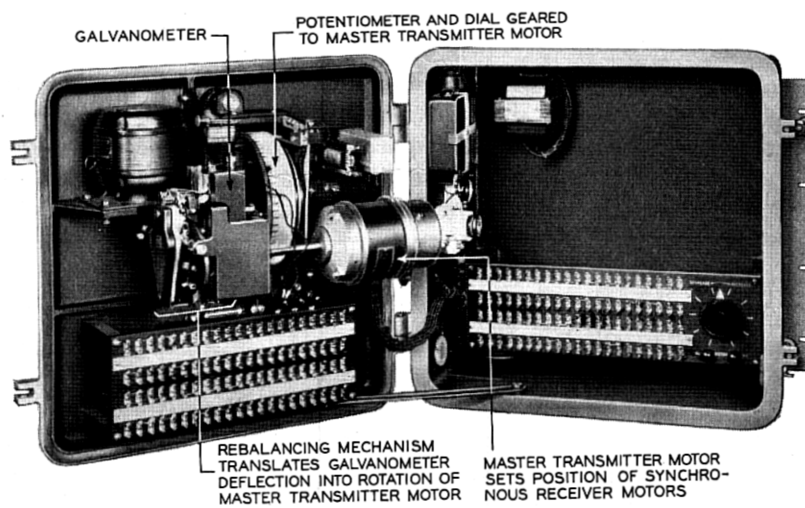

Fig. 13—Flat gain master controller.

to be regulated forms one arm of a Wheatstone bridge. This bridge is designed for automatic self-balancing and the mechanical motion required for establishing the balance has been made to adjust the gain of the amplifiers. The d-c. resistance of the pilot wire gives an accurate indication of the temperature of the carrier pairs which determines their attenuation to a close approximation. The motion of the bridge mechanism is communicated to the repeater amplifiers by means of self-synchronizing motors, a master motor being associated with the bridge and an individual motor with each amplifier.

With aerial cable a flat gain correction must be made at every repeater. With underground cable the flat gain correction may be

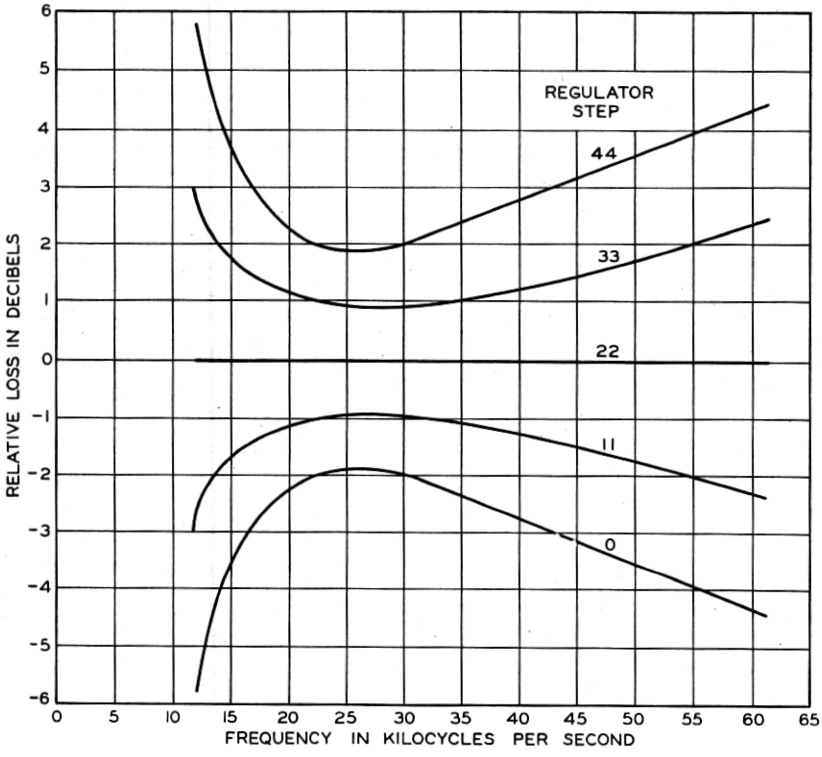

Fig. 14—Characteristics of twist regulator networks.

omitted at some repeater points. Figure 13 shows a master controller with its galvanometer, driving motor, and self-synchronizing motor. The air condenser in the feedback circuit of Fig. 8 makes this correction. The small self-synchronizing motor which may be seen in this figure is geared to the condenser and it moves the air condenser corresponding to the motion of the master motor. The resulting change in repeater gain is virtually the same for all frequencies in the transmitted band. In Fig. 10 the repeater gain is plotted against frequency for three angular positions of the condenser.

As was mentioned earlier, an additional correction for the residual effect or "twist" is required about every six repeaters to supplement the flat gain adjustment. This distortion is a function of frequency and has been found to vary from cable to cable. A network the characteristics of which are shown in Fig. 14 has been developed to meet this condition. Certain fixed resistances in the network are selected to correspond to the length and twist characteristic of the cable section considered. A variable resistance in the network is adjusted automatically using a control similar to the flat gain regulator. Figure 15 gives the transmission characteristics of a 150-mile regulator-controlled circuit under two temperature conditions.

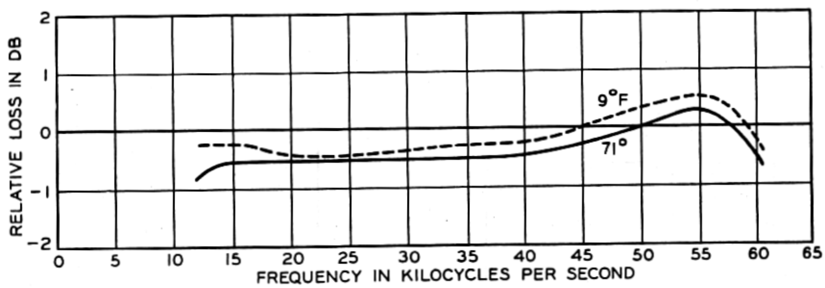

Fig. 15—Overall transmission-frequency characteristic of 150-mile line.

Auxiliary Repeater Stations

Cable carrier systems are expected to be used largely on existing toll cable routes which now carry voice-frequency circuits. The average spacing of the stations housing the voice-frequency repeaters on these routes is about 50 miles. The same buildings with their power plants will also care for the cable carrier repeaters. Since the maximum spacing for the carrier repeaters is about 19 miles, additional carrier repeaters must be provided at intermediate stations (two is the usual number). The various design features of the equipment to be located in these stations have been made the subject of extensive development work and field tests. These stations are designed to function with a minimum of attention and are visited at intervals for routine testing work or as required by some emergency, but resident maintenance forces are not planned for them. The present equipment is expected to be suitable not only for auxiliary stations on existing cable routes but also for cases where a greater spacing than 50 miles between the attended stations may be desired on new routes.

A voice-frequency repeater station for a single cable and a cable carrier auxiliary station are shown to approximately the same scale in Figs. 16a and 16b, respectively. Many of the existing voice-frequency stations are even larger than that shown in Fig. 16a. The auxiliary building shown in Fig. 16b has about 600 feet of floor space

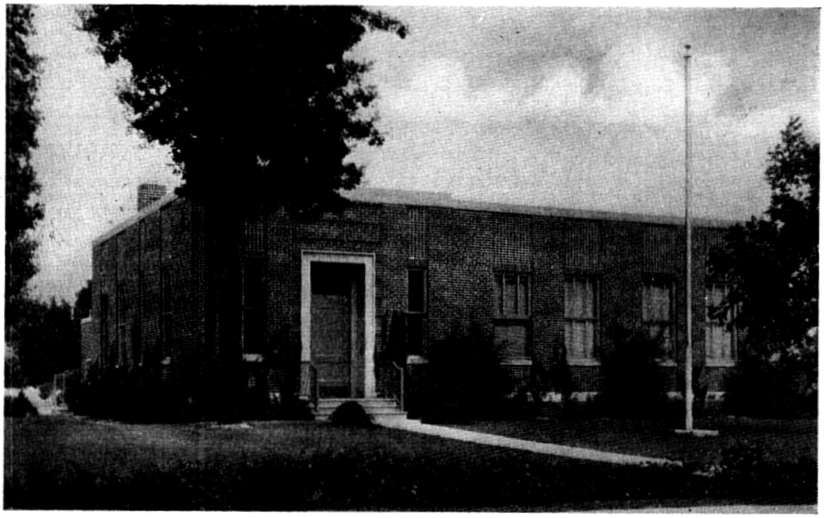

Fig. 16*a*—Voice frequency repeater station on single cable route.

with a ceiling height sufficient to take care of 11′6″ relay racks. This building will house 100 repeaters with necessary auxiliary equipment, thus providing ultimately for a total of 1200 carrier circuits. The interior of a typical auxiliary station is shown in Fig. 17.

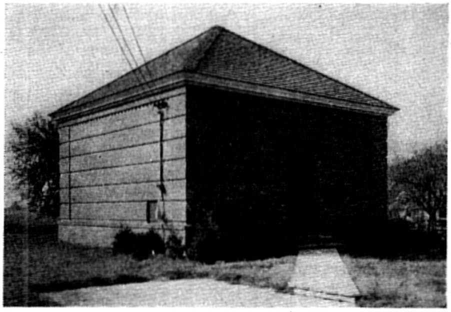

Fig. 16*b*—Auxiliary cable carrier repeater station.

The main power plant for the repeaters consists of a 152-volt storage battery, which is continuously floated across a grid-controlled rectifier fed from the 60-cycle power mains. The voltage of the entire battery supplies the plate voltage for the tubes. Each amplifier requires about 22 volts for the tube heaters and this is obtained by dividing the battery into seven sections, each section supplying several amplifiers in parallel. Additional power supplies of 55-volt alternating

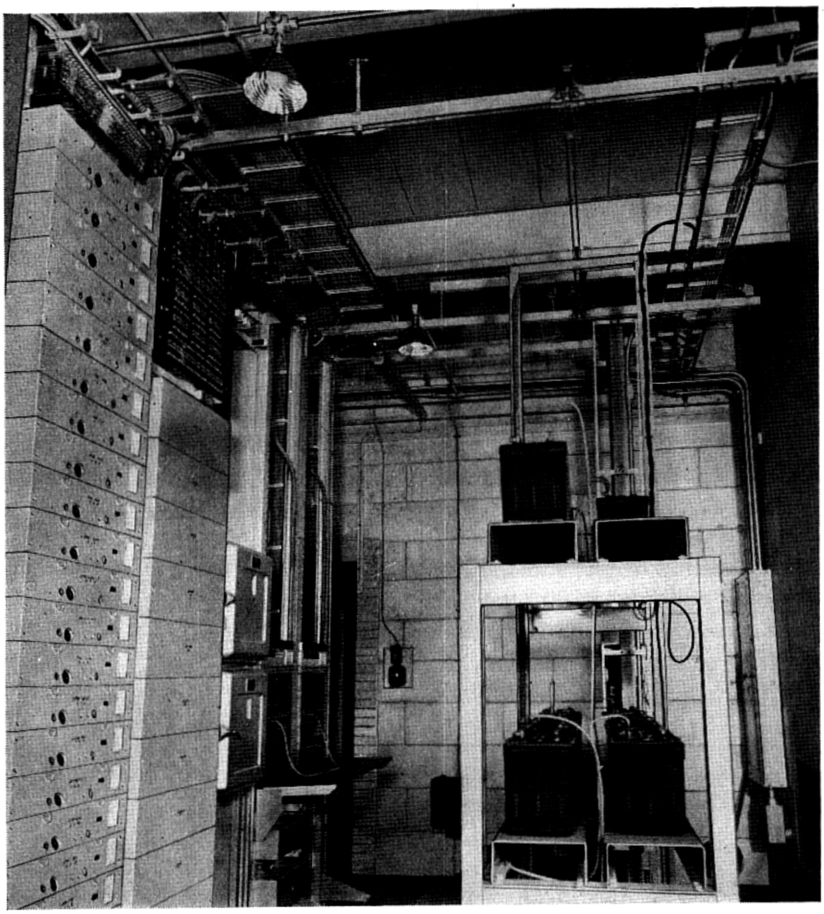

Fig. 17—Interior of auxiliary repeater station.

current and 140-volt direct current are required for the regulator system.

In the station, there are alarm circuits, which signal the nearest attended office if trouble develops. There are alarms for blown fuses, high or low battery voltages, power failures, etc. A telephone order wire to the nearest attended station is provided for the maintenance force.

In addition to the line amplifiers with their regulating equipment, there are racks mounting the crosstalk balancing coils. There are also sealed terminal units between the outside cable or the balancing units and the office cable. These furnish access to the line or equipment through jacks.

Terminals

The minimum distance over which a cable carrier system can be operated economically is determined in large measure by the cost of the terminal apparatus. Hence, the field of usefulness of the system is greatly increased by keeping the terminal cost as low as is consistent with satisfactory performance. Numerous developments during the past few years in connection with modulation, filtering and methods of carrier supply have all contributed materially toward this end. At the same time, the standards of performance have not only been maintained, but in many respects substantially improved.

Channel and Group Modulation

In the design of the terminals for the type K system, a number of circuit arrangements were considered, the final choice being influenced to a considerable extent by the conditions imposed upon the filters. As noted above, the desirability of using the channel terminal equipment in other broad-band systems, such as those for open-wire or coaxial cable, was also an important factor. The circuit arrangements selected have a first stage of modulation which raises the voice frequencies of the 12 channels up to a range of 60 to 108 kilocycles. This range is favorable to the use of crystal type band filters,[7] which have transmission characteristics superior to the coil and condenser type and seem to be no more costly. For the type K system, a single stage of group modulation shifts the frequencies to the range required on the line, 12 to 60 kilocycles, and a similar stage at the receiving end returns them to the 60 to 108-kc. range. Other carrier systems will also use the 60 to 108-kc. channels and by group modulation shift them to the desired position in the frequency spectrum.

The band filter occupies a space on the relay rack equal to 1/8 of that required by the coil and condenser type which was used in the earlier model of this system. Its attenuation characteristic in the transmitting region is flat to within 1 db over a range of about 3100 cycles. Immediately outside of this range the attenuation rises very rapidly, thus permitting very efficient use of the frequency spectrum.

Another new device on the terminal is the copper-oxide unit used in the modulating process. These units are expected to show a stability of the same order as that of coils and condensers, and require practically no maintenance as compared to vacuum tubes.

The translation of the channels from the 60 to 108-kc. range to the position required for cable carrier, 12 to 60 kilocycles, is made by a stage of group modulation. A copper-oxide group modulator is used and a carrier frequency of 120 kilocycles. The reverse of this process in a similar group demodulator at the receiving end steps the frequency back to its original range, 60 to 108 kilocycles. These processes of modulation take place at points of low-energy level in the circuit with a comparatively high level of carrier, so that the inter-channel crosstalk which results from unwanted products of modulation is unobjectionable. Low-pass filters are inserted after the group modulator and demodulator, and amplifiers with flat gain characteristics are supplied to raise the levels of the output currents of the group modulators or demodulators.

Carrier Supply

The carrier frequencies which are required at a terminal are obtained from the harmonics of a base frequency. The carrier supply system is common to as many as 10 systems in one office. This simplification was made possible by the selection of the channel frequencies as multiples of a base frequency, 4 kilocycles being chosen for this system. This base frequency is produced by an oscillator in which the control element is a tuning fork, the whole unit being designed to have the necessary output and frequency stabilities. The output of the oscillator is amplified and fed to a circuit which produces the desired harmonics. All of the carrier frequencies which are required for the different channels as well as for group modulation and demodulation are obtained from these harmonics. A small coil with a permalloy core is the important agent in this process.[8]

Failure of the 4-kc. supply, or failure of the 120-kc. supply used for group modulation, would cause failure in the channels of all systems operating from this supply. Provision is made for such a contingency by an emergency carrier supply which is automatically switched into service when the regular supply fails. This reserve source duplicates all of the parts of the regular supply, 4-kc. fork, amplifier, harmonic producer, and amplifier for the 120-kc. carrier.

Assembly

The different panel units which make up the terminal of a type K system are assembled on a functional basis with similar panels of other K systems, the channel modulator-demodulator panels in one bay, the carrier supply in a second, the group modulator and demodulator in a third, etc. The compactness of the equipment makes it possible to mount the modulators and demodulators for 18 channels on one 11 ft. 6 in. bay 19 inches wide.

Signaling

The same type of ringdown signaling equipment is used with the channels of this system as with the voice-frequency toll circuits. A 1000-cycle tone, interrupted 20 times per second, is impressed on a channel terminal, modulated, and transmitted over the carrier system in the allotted channel band. At the far end, it is demodulated to operate the receiving end of the standard voice-frequency signaling circuit, or to be transmitted along an extended voice-frequency circuit to its terminal.

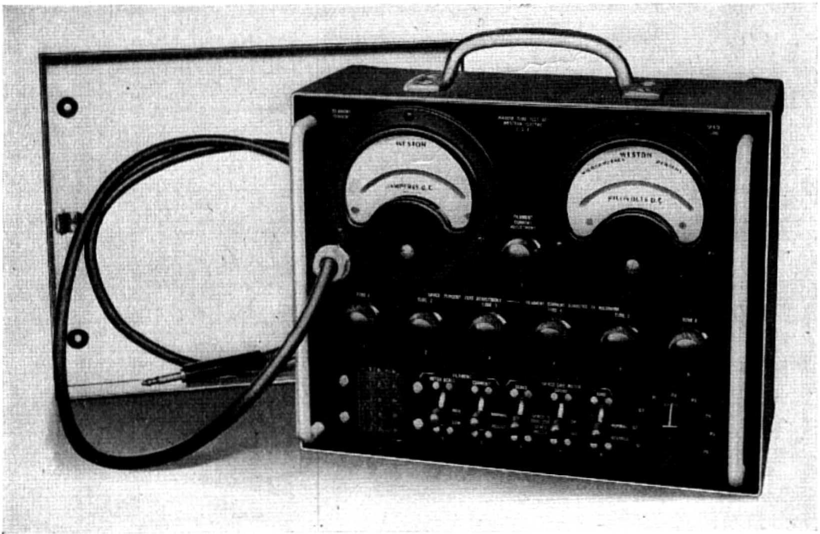

Fig. 18—Vacuum tube test set.

Telegraph and Program Applications

Voice-frequency telegraph can be superimposed on any of the carrier channels as is now done on the three-channel open-wire systems. Equipment is being developed to include a program channel on the cable carrier system. This will be done by devoting to the program circuit the frequency space occupied by two of the 4-kc. speech bands.

System Maintenance

Arrangements are provided whereby the tubes may be tested on a routine basis as has been done in voice-frequency practice. The amplifier panels, however, are provided with test jacks which are con-

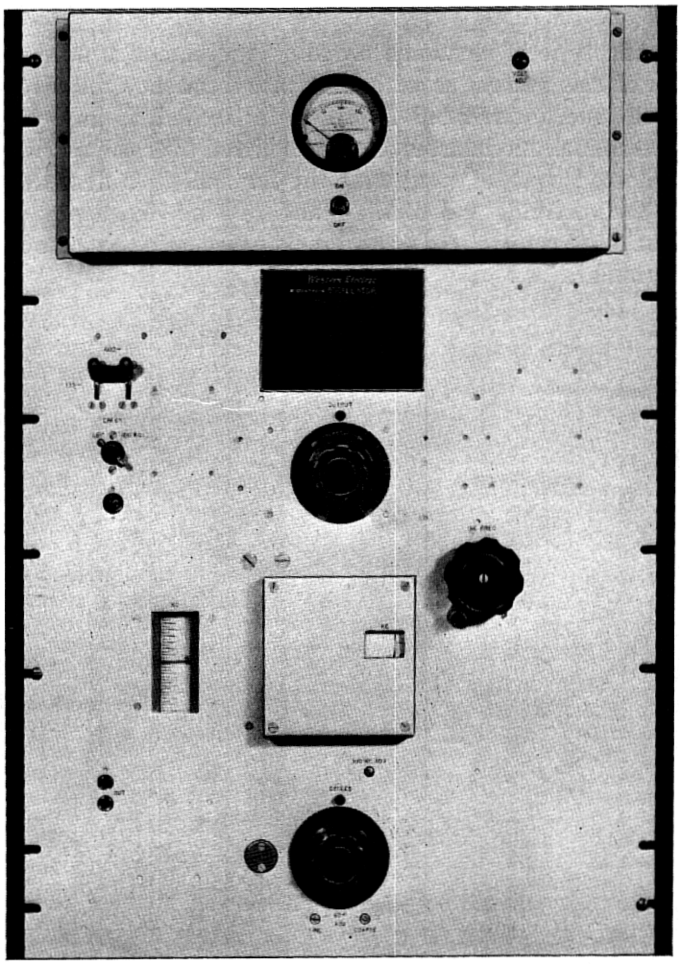

Fig. 19—Testing oscillator.

nected to resistances in the plate circuits. A reading of the voltage across the resistance gives a measure of the plate current for the associated tube without disturbing the amplifier performance while the amplifier is in service. A portable tube testing set, Fig. 18, has been designed for this measurement.

Provision is being made for the removal of an amplifier from an active circuit without interruption of service. A spare amplifier at each repeater station can be substituted for the active one by connecting it to jacks at the sealed terminal and operating associated relays to make a quick transfer.

Apparatus is also furnished which permits the substitution of a new link between attended points for one which develops trouble. A complete high-frequency circuit for each direction of transmission will generally be reserved as a spare. It can be substituted for any working

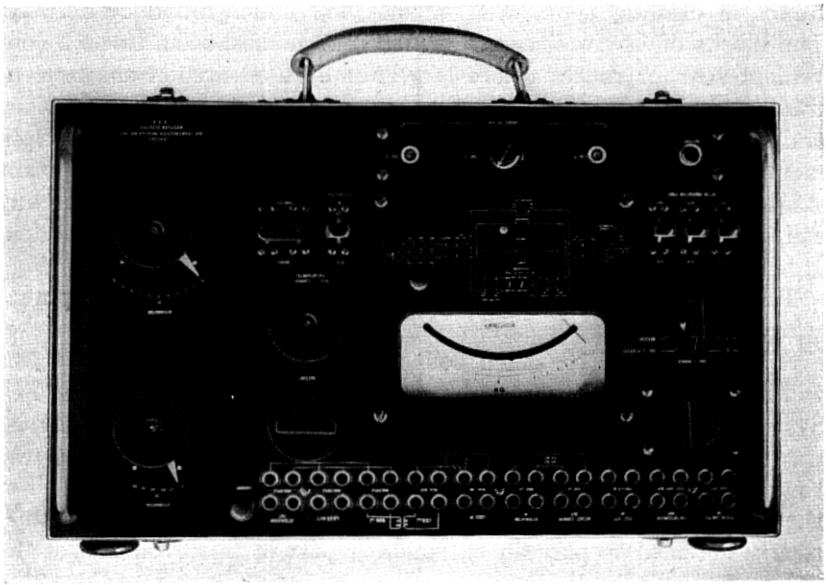

Fig. 20—Transmission measuring set.

high-frequency circuit without interfering with service by paralleling the transmitting ends of the spare and working circuits and patching the receiving ends through relays. The operation of a key controlling these relays substitutes the spare circuit for the working one with a transient disturbance of but 1 or 2 milliseconds.

Three pilot frequencies, 15.9, 27.9 and 55.9 kilocycles, which are produced at the transmitting terminals, may be used to check the levels at the main repeater points and the receiving terminals. This is done by means of a special testing circuit which can be bridged across a pair to detect the level of the pilots without interference to service.

A heterodyne oscillator having a frequency range from 60 cycles to 150 kilocycles has been developed for use in testing this and other carrier systems. Its frequency is calibrated at 60 cycles against the power mains and at 100 kilocycles against a quartz crystal. This oscillator is shown in Fig. 19. A portable test set, developed for measuring transmission gains and losses with high precision, is shown with the cover removed in Fig. 20.

Conclusion

The type K system makes possible the application of carrier to toll cables of existing type, whether installed underground or aerially. The blocks of 12 circuits each, which it furnishes, seem to be a convenient size for routes where large numbers of circuits are concentrated. It is to be expected, of course, that substantial modifications and improvements will be made in this system through further development effort. In its present form, however, it constitutes an important stage in the history of carrier development. Plans already under way call for the application of large numbers of such systems to meet rapid growth in long distance traffic.

This new system forms merely one phase of a concerted development effort on broad-band carrier transmission systems.[9, 10] There is every indication that, taken collectively, these broad-band systems will have far reaching effects upon the toll telephone plant of the Bell System. A transition is already under way from the time when carrier was used only on open wire, and comprised only a small part of the toll plant, to a time when carrier systems will furnish a major part of the toll circuit mileage of the Bell System. The type K system is clearly destined to play an outstanding part in this evolution of the toll plant along carrier lines.

References

1. "Carrier in Cable" by A. B. Clark and B. W. Kendall, *Electrical Engineering*, Vol. 52, page 477, July 1933; also *Bell Sys. Tech. Jour.*, Vol. XII, p. 251, July 1933.
2. "Carrier Systems on Long Distance Telephone Lines" by H. A. Affel, C. S. Demarest and C. W. Green, *Bell Sys. Tech. Jour.*, Vol. VII, pages 564–629, July 1928; also *Electrical Engineering*, Vol. 47, pp. 1360–1367, October 1928.
3. "Transmitted Frequency Range for Circuits in Broad Band Systems" by H. A. Affel, *Bell Sys. Tech. Jour.*, Vol. XVI, p. 487, October 1937.
4. A. G. Chapman, U. S. Pat. No. 1863651; M. A. Weaver and O. H. Coolidge, U. S. Pat. No. 2008061; M. A. Weaver, U. S. Pat. No. 2080217.
5. "The Time Factor in Telephone Transmission" by O. B. Blackwell, *A.I.E.E. Transactions*, Vol. 51, pages 141–147, March, 1932; also *Bell Sys. Tech. Jour.*, Vol. XI, pp. 53–66, January 1932.
6. "Stabilized Feed-Back Amplifiers" by H. S. Black, *Electrical Engineering*, Vol. 53, p. 114, January 1934.

7. "Electrical Wave Filters Employing Quartz Crystals as Elements" by W. P. Mason, *Bell Sys. Tech. Jour.*, Vol. XIII, p. 405, July 1934.
8. "Magnetic Generation of a Group of Harmonics" by E. Peterson, J. M. Manley and L. R. Wrathall, *Electrical Engineering*, Vol. 56, No. 8, p. 995, August 1937; also *Bell Sys. Tech. Jour.*, October 1937.
9. "Wide-Band Transmission in Sheathed Conductors" by O. B. Blackwell, *Bell Telephone Quarterly*, Vol. XIV, p. 145, July 1935.
10. "Systems for Wide-Band Transmission Over Coaxial Lines" by L. Espenschied and M. E. Strieby, *Electrical Engineering*, Vol. 53, pp. 1371–1380, October 1934; also *Bell Sys. Tech. Jour.*, Vol. XIII, pp. 654–679, October 1934.
11. "Modern Systems of Multi-Channel Telephony on Cables" by A. S. Angwin and R. A. Mack, *Journal of the Inst. of Electrical Engineers*, Vol. 81, No. 941, p. 573, November 1937.