Line Problems in the Development of the Twelve-Channel Open-Wire Carrier System *

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The development of the type J twelve-channel carrier telephone system for open-wire lines required an increase of nearly 5 to 1 in the transmission frequency range of the lines. In the provision of suitable line facilities a number of new problems were encountered with respect to attenuation, noise and crosstalk. Methods for meeting these problems and the results obtained are described.

Introduction

A NEW carrier telephone system for open-wire telephone lines has been described recently.[1] This system increases the number of two-way telephone circuits which can be obtained on a single pair of wires from the previous maximum of 4 to a total of 16. This has been achieved by extending the frequency range from a maximum of about 30 kilocycles to more than 140 kilocycles. The exploitation of this new range of frequencies on open wire has involved the solution of a number of interesting problems, among which are these:

(1) Not only does the attenuation of an open-wire line under ordinary weather conditions rise substantially with frequency but extremely large increases in attenuation occur at the higher frequencies when ice forms on the wires.[2, 3] In spite of these effects a high degree of stability of transmission has been secured on all channels by the provision of automatic control of repeater gain and equalization.

(2) New crosstalk problems created by the extension of the frequency range have been solved by the development of transposition designs with numbers of transpositions not greatly in excess of those employed for the lower frequency systems. Problems have also arisen in controlling the crosstalk around the repeaters and in reducing the effect of impedance departures between the line circuits and the equipment.

Frequency Allocations

The type J system operates on circuits on which type C carrier systems were already operating in the frequency range up to about 30 kilocycles. To provide enough frequency separation between the two

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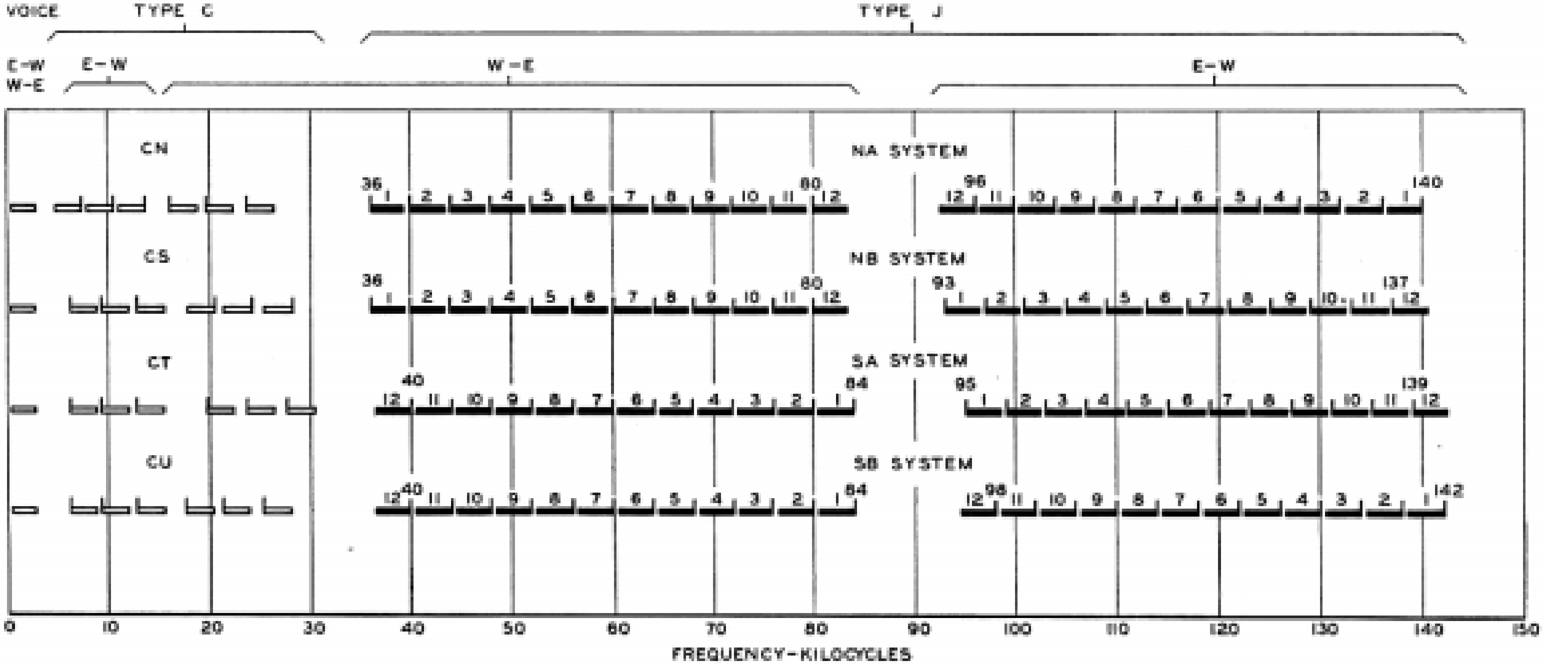
[1] Reference numbers refer to the list of references appearing at the end of the article.



NOTE: E-W ALSO IMPLIES TRANSMISSION N-S AND W-E IMPLIES S-N

Fig. 1—Frequency allocation.

systems the lower frequency limit of the J system was set at 36 kilocycles; the necessary frequency space for 12 channels in each direction set the upper limit at about 140 kilocycles. This range is split into two parts, one used for transmission in one direction and the other for the opposite direction. Figure 1 illustrates the relation of the frequency bands occupied by the type J and type C systems and the voice-frequency channel. Different "staggered" locations of the frequency bands are to be employed in order to simplify crosstalk problems.

Filters are used for separation of the type J from the type C and lower frequency facilities on the same pair of wires. This separation is done by means of a combination of high and low pass filters which split apart the frequency ranges above and below the band between 30 and 36 kilocycles. To simplify the design of these filters, the low frequency group of the type J system is transmitted in the same direction as the high frequency group of the type C system. This arrangement of transmitting certain frequencies in a particular direction is generally used throughout the telephone plant in order to avoid serious crosstalk difficulties. Accordingly, with few exceptions, west to east transmission or south to north transmission takes place in the same frequency bands throughout the country and similarly, east to west or north to south transmission employs the same frequency bands. These are indicated in Fig. 1.

LINE ATTENUATION

An open-wire pair affords the lowest loss transmission medium of any conductor employed in the telephone plant. It is, however, peculiarly subject to the effect of weather, which may cause large and often rapid changes in the attenuation. In consequence, some form of gain regulation is required.

Even for carrier systems operating up to 30 kilocycles, manual regulation is inadequate for the longer systems and automatic devices have been provided for most systems over 500 miles in length. The attenuation changes caused by changes in resistance of the wire with temperature or by changes in the shunt losses when insulators become wet are much larger at the higher frequencies of the J system, and therefore, an automatic regulating scheme is required. Tests were made on open-wire circuits to determine more precisely the characteristics needed for such a regulator. During sleet storms, when wires are covered with ice, the increases in attenuation are far beyond any caused by rain. Figure 2 shows increases which may be caused by ice as compared with the normal dry and wet weather values.

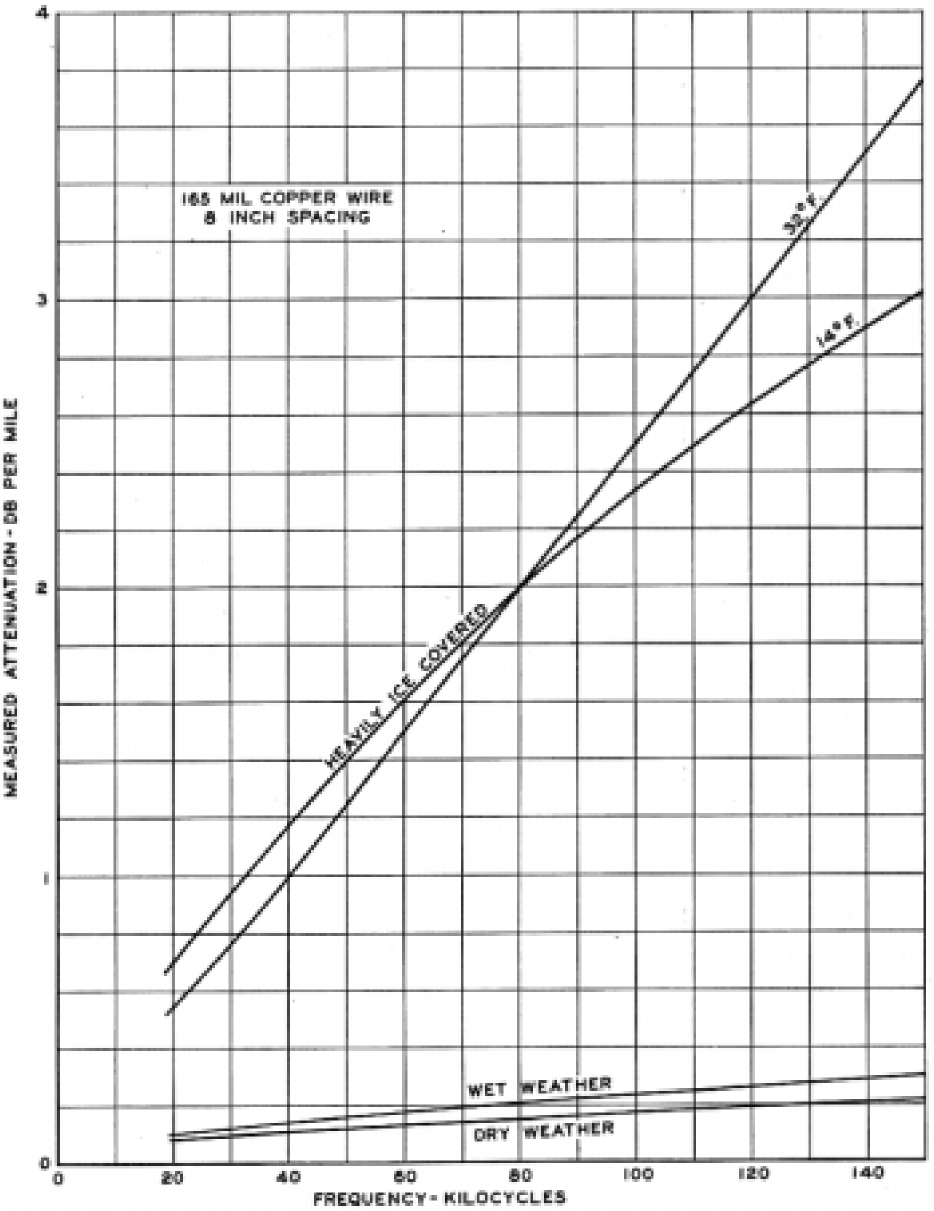


Fig. 2—Attenuation variation with weather.

The deposits on the wire may be actual ice, or in some cases wet snow or frost adhering to the wire. Figure 3 shows an example of such deposits. Theory shows that the increase in attenuation is caused by energy losses in the ice itself and that leakage across the insulators is usually a negligible factor.

An extensive survey of the effects of ice has been carried on at various points throughout the country during the past four years and a large amount of information has been accumulated. These tests have shown that the shape of the attenuation-frequency characteristic differs considerably for different ice formations and even if the ice deposit remains the same for a time, the attenuation-frequency characteristic may vary with temperature as in Fig. 2. The two upper curves of the figure were measured at different times during the same storm. There was no apparent change in deposit between the two measurements. This change in shape of the characteristic, of course, makes the regulation problem more difficult. In spite of the extreme severity of ice effects in certain regions, it is expected that satisfactory reliability will be obtained on type J systems by placing the repeaters sufficiently close together.

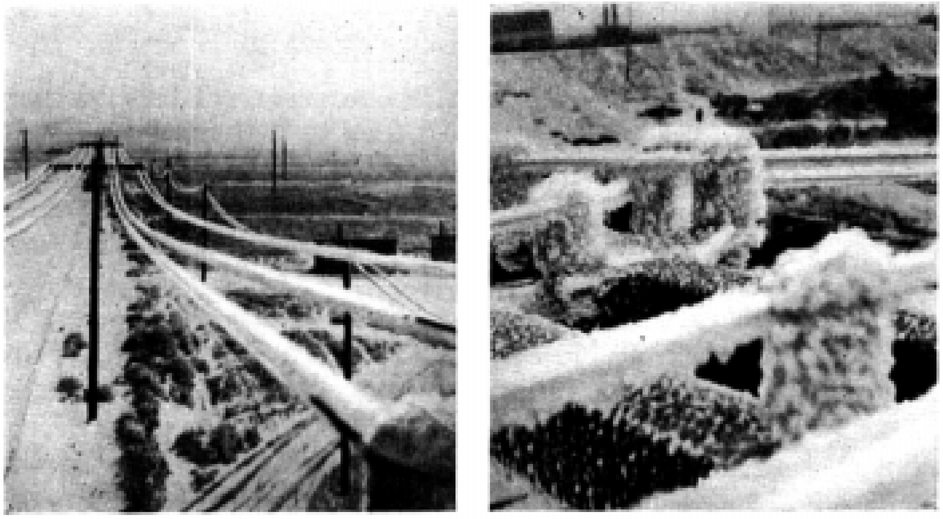


Fig. 3—Ice on wires and insulators near Amarillo, Texas.

REGULATION PROBLEM

In the first type J systems the regulator, actuated by a single pilot frequency in each direction, compensates for the attenuation changes caused by temperature and wet weather.

The required varieties of attenuation slopes with ice on the wires could not be provided by a simple regulator. Hence provision is to be made in later designs for a regulator with variable slope controlled by two pilot frequencies which is expected to be satisfactory in areas subjected to sleet conditions. The regulating range will also be increased so that a completely automatic control of gain up to about 75 db will be available.

It was found that during periods when ice coated the wires the circuit noise measured at the end of a repeater section usually decreased as the attenuation increased. This is important because otherwise the extra increase in the repeater gain to take care of the higher attenuation at such times would make the noise excessive. The study of ice conditions throughout the country which has been carried on and is still continuing will be useful in laying out repeater stations along some of the routes which eventually will be candidates for the application of type J systems.

OPEN-WIRE CROSSTALK [4]

The crosstalk problem on open-wire lines is one of the most important. Crosstalk is controlled by transpositions which are introduced into the various pairs in accordance with a predetermined design. The creation of the necessary designs requires consideration both of the complex theory of transpositions and measurements on lines constructed by practical methods.

However, the design of transposition systems is considerably simplified by the use of different frequencies for the two directions of transmission. The only crosstalk between systems which is directly important is that known as far-end crosstalk, which is that between a talker at one end of one circuit and a listener at the opposite or far end of another. Near-end crosstalk, which is that between a talker and a listener at the same or near ends of two circuits, becomes a source of interference between circuits only when portions of it appear as far-end crosstalk because of reflections at points of impedance irregularity in the circuits.

Because of the high cost of a transposition design to keep both near-end and far-end crosstalk down to small values, only small reflections are permitted where open-wire and cable meet, or where circuits are terminated in equipment. A number of the difficulties which had to be overcome to attain small reflections are discussed later in the paper. With this control the transposition designer can concentrate most of his attention on far-end crosstalk, the near-end crosstalk requirements are relaxed, and a cheaper transposition arrangement can be used.

What can happen when reflection occurs may be seen by comparison of the near-end and far-end crosstalk curves in Fig. 4. The similarity in the shapes of the two curves, and particularly the fact that the peaks occur at the same frequencies, show that what appears to be far-end crosstalk is in this case mostly reflected near-end crosstalk. It is for pair combinations such as this one, where the near-end crosstalk is much larger than the far-end, that the closest control of reflection effects is required. With the values of reflection realized in the J system, reflected crosstalk will ordinarily be unimportant.

To obtain satisfactory crosstalk conditions at the higher frequencies some changes in line construction are necessary. To use type J carrier systems on existing open-wire routes, methods were devised for modifying the line construction in as economical a manner as possible.

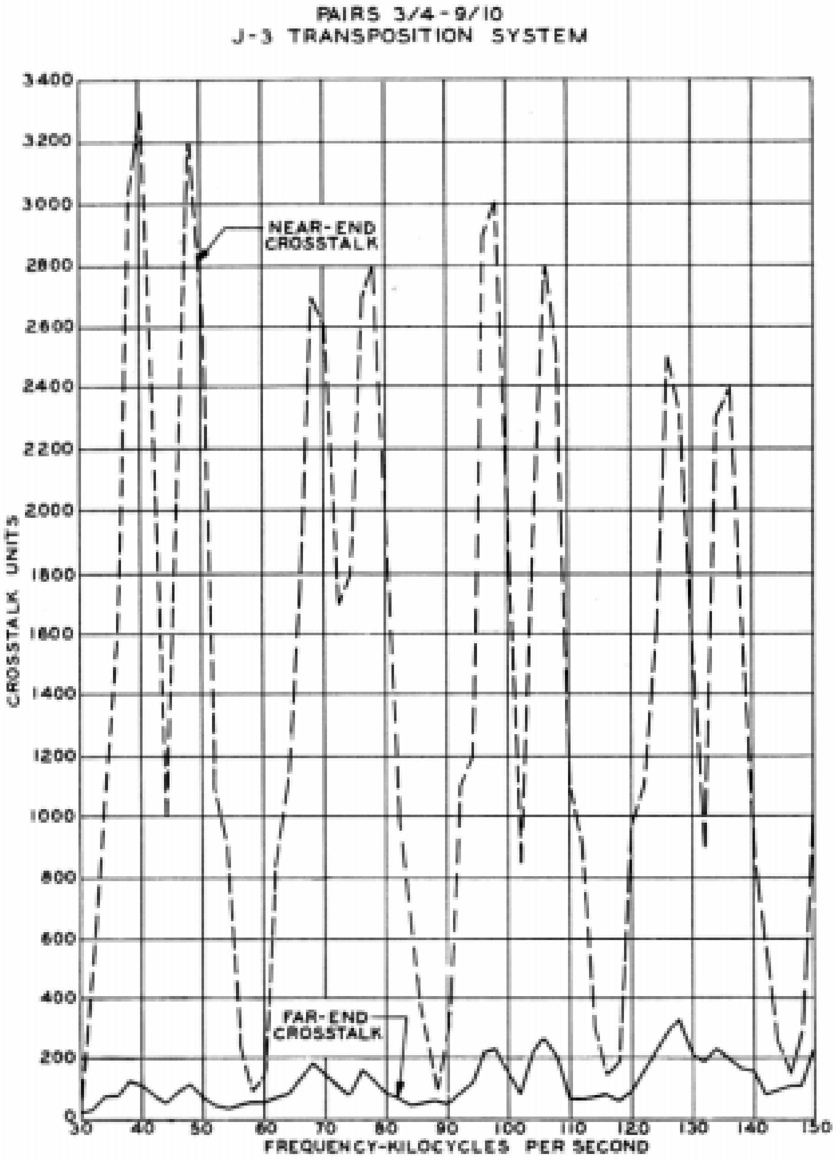
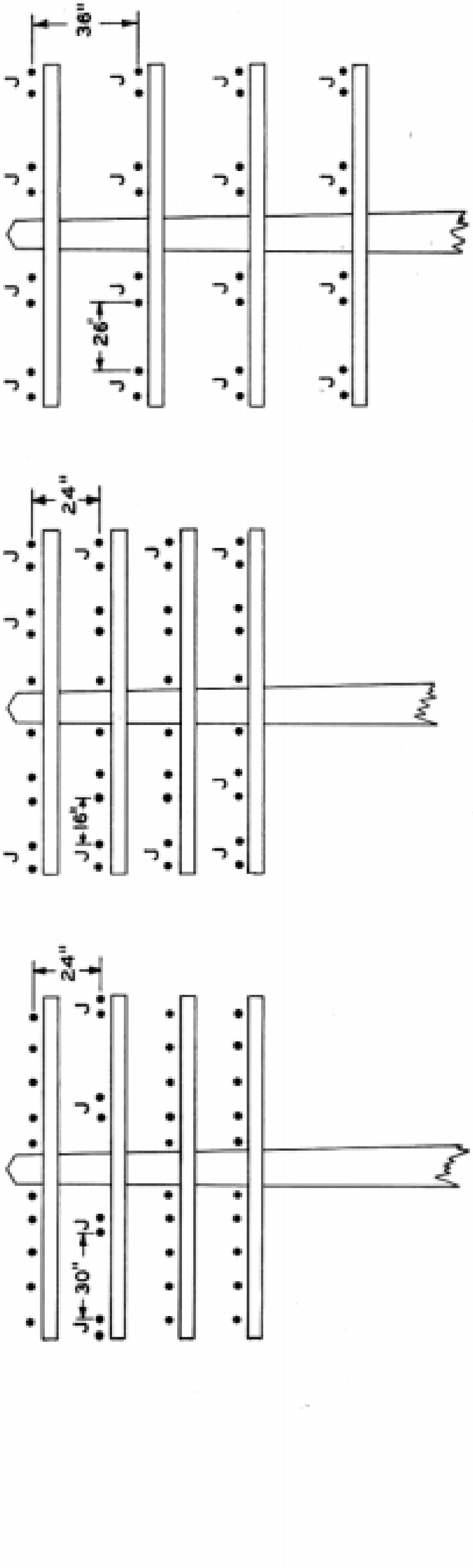


Fig. 4—Near-end and far-end crosstalk—J-3 transposition system.

For new lines, such as the new part of the Fourth Transcontinental line,[5] advantage was taken of the greater degree of freedom in structural design which was possible.

Figure 5 shows three types of open-wire pole head configuration



Modified "Alternate Arm" line
12" spaced phantomed sides
except
4 J pairs respaced to 6"
J-1 transposition system

Modified "K-8" line
8" spaced
non-phantomed pairs
K-8-2 transposition system

New lines
8" spaced
non-phantomed pairs
J-2 or J-3
transposition system

Fig. 5—Three types of open-wire pole head configuration.

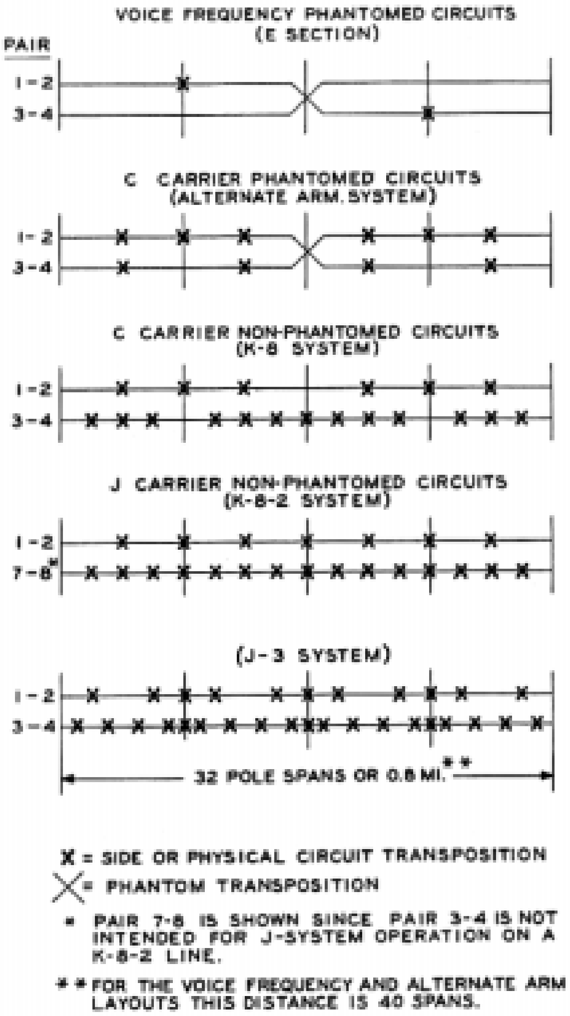
suitable for J system operation. The left-hand diagram shows a method of reconstructing part of one of the older types of open-wire lines built with 12-inch spacing between wires of the pairs and with the "Alternate Arm" transposition system which was developed for the use of type C systems on the side circuits of the horizontal phantom groups on alternate arms. This method is a flexible one in that one or more phantom groups may be converted at a time, as on the second crossarm shown. For such an application not only was removal of the phantoms and retransposition necessary, but the spacing of the two wires of each pair was reduced to 6 inches. This general method of construction was used for the Dallas-Houston and Dallas-San Antonio lines,[6] except that the 6-inch pairs were constructed with new wire on a new crossarm rather than by respacing 12-inch pairs.

Another common type of open-wire pole head configuration, the middle diagram of Fig. 5, is that made up of 8-inch spaced non-phantomed pairs transposed in accordance with the K-8 transposition system on an eight-span base. Through design studies supplemented with field experiments it was found that such a line could be converted for J systems much more cheaply than an Alternate Arm line. If J systems are restricted to the pairs on the outer ends of the crossarms, with two inner pairs, about one or two transposition changes in each pair per mile are enough. This scheme was followed in reconstructing the line between Charlotte, North Carolina, and West Palm Beach, Florida.

For new lines yet to be built, a greater degree of latitude in structural design is naturally possible. The right-hand diagram of Fig. 5 shows an open-wire pole head configuration designed to allow J systems to be operated on all of the pairs. The unique feature of this configuration is that, while 8-inch spacing is preserved between the wires of the various pairs, the adjacent non-pole pairs on a crossarm are separated by twenty-six inches and the crossarms by thirty-six inches. The reduction in coupling made possible by this increased spacing keeps the crosstalk for any combination of pairs down to a suitable value with transposition arrangements not necessarily more complicated than those employed for the other configurations. This type of construction was used for the new parts of the Fourth Transcontinental line.

Fig. 6 shows a comparison of the number of transpositions used in a typical section of open-wire line for various types of circuits from voice frequency phantomed circuits to non-phantomed circuits intended for J system operation. From the original arrangement where there was one transposition point in every ten spans, about

¼ mile, the number of transpositions for J carrier operation has been increased so that for the J-3 design, which was used for the new wires on the Fourth Transcontinental line, there are four transpositions in each eight-span interval and every pole is a potential transposition point.



X = SIDE OR PHYSICAL CIRCUIT TRANSPOSITION

╳ = PHANTOM TRANSPOSITION

* PAIR 7-8 IS SHOWN SINCE PAIR 3-4 IS NOT INTENDED FOR J-SYSTEM OPERATION ON A K-8-2 LINE.

** FOR THE VOICE FREQUENCY AND ALTERNATE ARM LAYOUTS THIS DISTANCE IS 40 SPANS.

Fig. 6—Illustrative transposition arrangements.

It may be seen from Fig. 6, however, that the number of transpositions required in pairs for J carrier operation is not necessarily larger than the number employed in systems intended for C carrier operation with a top frequency of 30 kilocycles. The superiority of the J system transposition arrangements as compared with those designed for C system operation results from the choice of specific arrangements which best limit the systematic effects for frequencies in the J system range.

Typical far-end crosstalk measured between 8-inch spaced pairs 11/12 and 19/20 on a new J-3 line and on a reconstructed K-8-2 line is shown by Fig. 7. The superiority of the new line with its fewer wires, greater pair separations, better transposition system and smaller irregularities is evident.

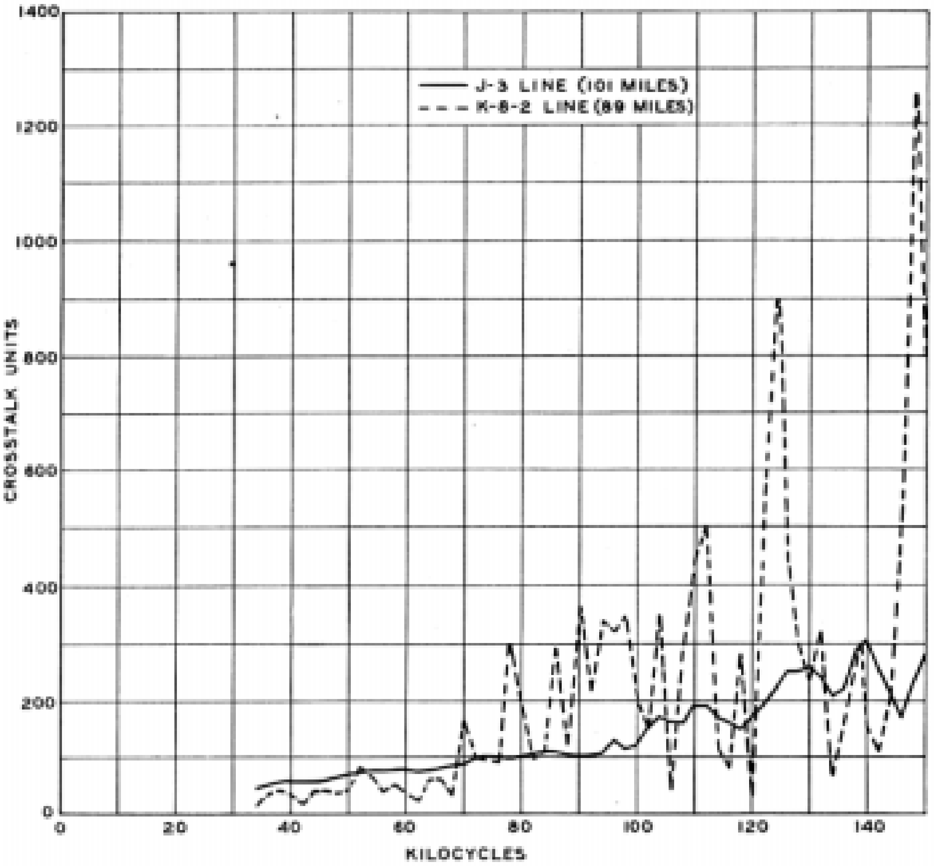
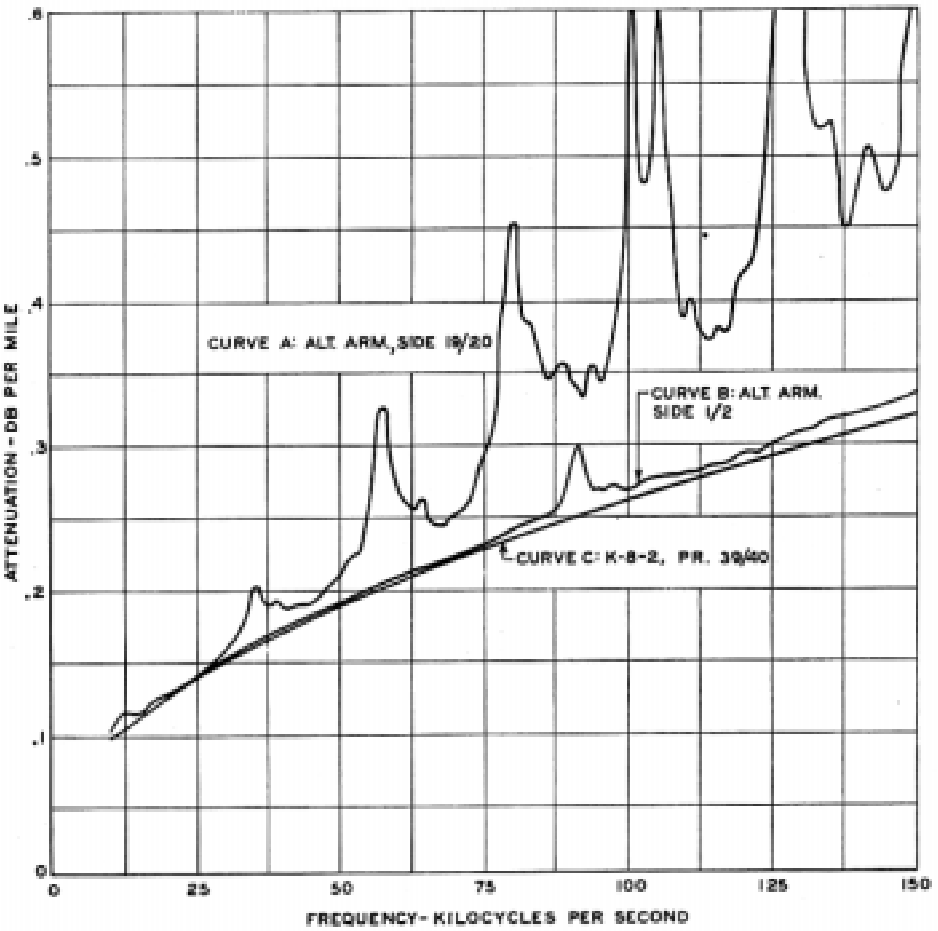


Fig. 7—Far-end crosstalk between 8-inch spaced pairs 11/12 and 19/20.

ABSORPTION EFFECTS

The attenuation of an open-wire pair may be quite unsatisfactory if there are what are known as absorption effects, caused by induction into surrounding circuits such that energy is absorbed in particular frequency bands and the attenuation of the pair increased. These effects, which depend on the transposition arrangements in the circuits, may cause objectionable transmission distortion at critical frequencies unless the transpositions are planned to avoid them. The same arrangements necessary to control crosstalk between J systems will automatically eliminate absorption effects with one exception. If only part of the pairs on a line are designated and transposed for J systems and the remaining pairs are not so transposed, absorption in a J pair can be caused by a nearby non-J pair. Consequently, consideration of the crosstalk relations at J frequencies between all of the pairs on the line cannot be avoided even though some of them will not be used for J systems.



Curves A and B: Side 19/20 and 1/2 respectively, on Alternate Arm line, 104 mil, 12-inch, 56.7 miles, 90° F. at Mascoutah, Ill.
Curve A is transposed for voice frequencies.
Curve B is transposed for carrier operation up to 30 kc.
Curve C is pair 39/40 on K-8-2 line, 104 mil, 8-inch, 68 miles, 50° F. and CS insulation between Denmark, S. C. and Rincon, Ga. Transposed for carrier operation up to 140 kc.

Fig. 8—Attenuation of open-wire pairs of different types.

Figure 8 illustrates the effect of absorption on three different pairs. Curves A and B show the absorption measured over the type J frequency range on a line of the Alternate Arm type. Curve A was obtained on a side circuit transposed for operation at frequencies only up to about 10 kilocycles. The absorption at frequencies above this becomes very large. Curve *B* shows the absorption present on one of the C carrier side circuits on the same line transposed for operation up to 30 kilocycles. Curve *C* shows how absorption disappears on a non-phantomed pair specially transposed for type J operation. If this pair were measured at much higher frequencies, similar absorption "bumps" would be found, perhaps at frequencies of 200–300 kilocycles or higher.

Since absorption effects depend on the systematic addition of crosstalk currents along a line, a continuous succession of identical transposition sections tends toward greater absorption while a random succession of different kinds of transposition sections of different lengths will reduce it. The Dallas-Longview J system is operating on an Alternate Arm side circuit, transposed for C carrier operation and without any modifications to adapt it for the higher frequencies. Because of the fortunately irregular succession of different transposition sections found here, it was possible to select, after tests, a pair with no serious absorption.

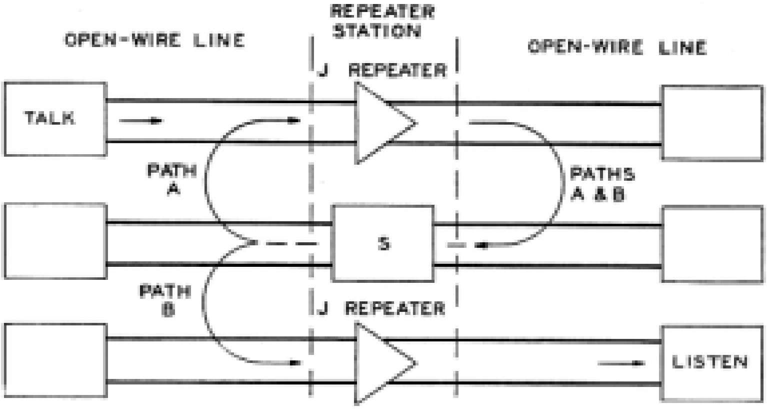
CONSTRUCTION IRREGULARITIES

With the new transposition designs, the systematic crosstalk resulting from the transposition arrangements has been reduced in nearly every case so far that the remaining crosstalk is controlled principally by construction irregularities. An important source of irregularity is the difference in sags of the various wires in each span of the line, particularly sag differences between the two wires of each pair. Another potentially important source of irregularity is the variation in the spacings between successive transposition poles. It is relatively easy to make this factor unimportant as compared with sag differences.

The large amount by which the crosstalk can be reduced by careful methods of construction coupled with the highly developed systematic transposition patterns is illustrated by the fact that between certain pairs the crosstalk in a 75-mile repeater section is reduced to a value which would be produced by a capacitance unbalance between them of less than 2 mmf, which is about the same in magnitude as the capacitance between wires of a foot of the open-wire pair. This large crosstalk reduction is in spite of the fact that at 140 kilocycles the phase change along an open-wire circuit is about 7° in a single span, the shortest distance between any two transpositions, and about 28° for the more common four-span interval.

INTERACTION CROSSTALK AT REPEATER POINTS

Another type of problem was introduced by what is known as interaction crosstalk. This is the crosstalk which occurs from one side to the other of a J repeater station. Figure 9 illustrates two paths which it may take. Path A shows the crosstalk from a system to itself which may cause transmission distortion or repeater singing while Path B is the path of crosstalk between different circuits. The essential feature of this interaction crosstalk is that, as Fig. 9 shows, the crosstalk path at a repeater station passes through the J repeater and hence the crosstalk is amplified by the repeater gain.



S-INDICATES A SUPPRESSION DEVICE

Fig. 9—Interaction crosstalk at a J repeater station.

The new problems of controlling this crosstalk were the result of larger magnitudes of crosstalk at the higher frequencies, the larger repeater gains and the fact that with more repeaters there were more points on a system where it could occur. Magnitudes of interaction crosstalk which had previously been thought of as inconsequential assumed a new importance. For instance, with the gain of about 75 db proposed for the repeater for use in sleet areas, an initial value of unamplified interaction crosstalk as low as 0.25 crosstalk unit would be magnified to 1400 units, which might considerably exceed the far-end crosstalk existing at the same time in one repeater section.

Several new methods for reducing this interaction crosstalk were devised. In the first place, in order to prevent direct coupling between the wires of the open-wire line on the two sides of the station, it was found necessary to cut a gap in the line. With the wires entirely removed for a distance usually of about eighty feet, the line is brought into the station from the two terminal poles by means of the lead-in cables.

It was also seen to be necessary to block the paths provided by the wires of the telephone line itself. For this purpose, crosstalk suppression filters were designed and built to be installed in all of the non-J circuits on the line. These give losses of the order of 70 db at 140 kilocycles not only in the metallic transmission circuits but also in other circuits, made up of various combinations of the line wires, which may conduct crosstalk currents through the stations.

In addition to the crosstalk suppression filters and in order to provide an extra margin of safety against interaction crosstalk currents which might find their way through the repeater station by stray paths, longitudinal choke coils have been connected at the pole heads between the open wires and the lead-in cables. These coils do not disturb ordinary transmission but add high impedance in the longitudinal circuits.

These measures for controlling interaction crosstalk have been found to be adequate so far as the telephone line is concerned. At an occasional J repeater station, however, located on a right-of-way occupied by several pole lines, there is found another pole line paralleling the telephone line with a separation sometimes as little as 2 to 5 feet between the nearest wires of the two lines. Such wires provide other interaction crosstalk paths past the repeater station and impair the effectiveness of suppression measures installed in the line on which the J system is operated. The by-passing effects of such a foreign line can be controlled by crosstalk suppression devices similar to those used in the telephone line wires.

Figure 10 shows a comparison of the interaction crosstalk measured at a J repeater station before any suppression measures were installed, the other wires of the line being continuous at the station location, with the corresponding interaction crosstalk when the line was run through the suppression devices in the station. The values shown would be amplified by the gain of the J repeater on the disturbed circuit before they reached the listener. The effect of the by-passing foreign line is illustrated by the difference between the middle and bottom curves, the bottom curve showing the measured crosstalk when the by-passing line was cut to simulate the effect of suppression measures in it.

STAGGERED SYSTEMS

It would not be possible with the open-wire line configurations now in use to design transposition arrangements that would permit the operation of identical J systems on all pairs. For this reason four types of J systems with different channel carrier frequency allocations will be provided in the future. The frequency assignments for these systems are shown in Fig. 1.

The "staggering" advantage, or effective crosstalk reduction between systems, is effected because (1) the inversion or displacement of channels in the different systems with respect to each other makes the crosstalk unintelligible and (2) the reduction of the overlap between channels results in less energy being transferred between them by crosstalk. The net benefits of "staggering" obtained by the allocations shown in Fig. 1 range from about 6 to 16 db.

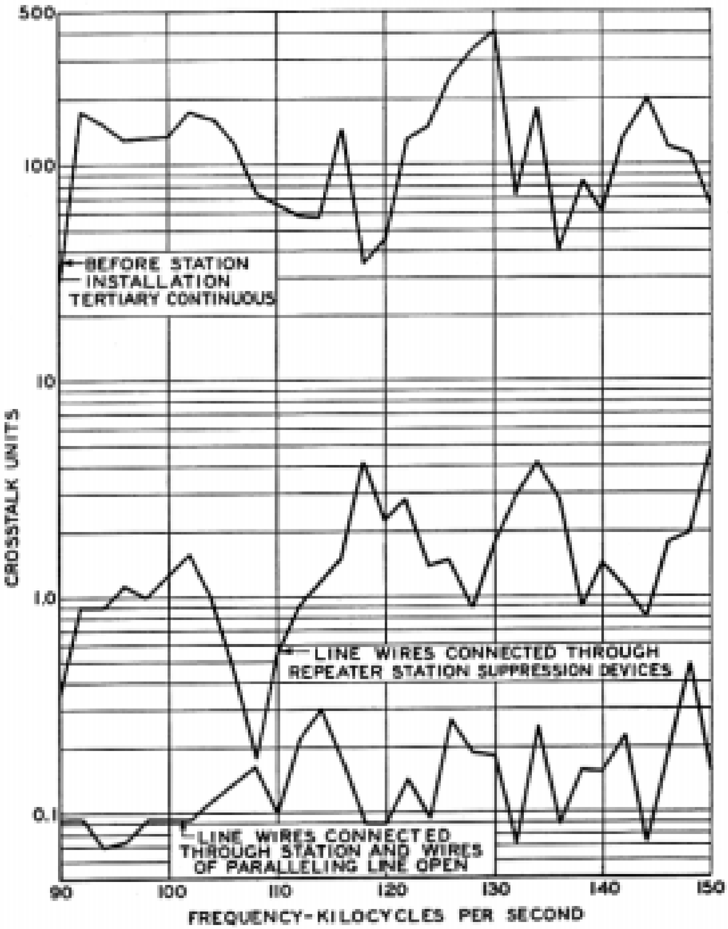


Fig. 10—Unamplified interaction crosstalk between two J circuits at an auxiliary repeater station.

The most effective pair assignments for the four types of J systems can best be obtained from actual crosstalk data on the particular sections of line involved. The "staggering" advantages obtained are sufficient so that the highest remaining crosstalk will usually occur between the like J systems operating on non-adjacent pairs.

NOISE

Observed external sources of noise in J systems are atmospheric static, dust storms, radio stations, power line carrier and power supply systems.

Of these possible sources the more important will usually be atmospheric static which will be greatest during the summer months. In regions where dust storms occur, their effects are expected to exceed that of atmospheric static but will be more likely to occur during the winter and early spring.

The following table shows values of noise at 140 kilocycles, caused by atmospheric static, found at the open-wire line terminals of one repeater section; the values are those which it is expected will be exceeded during one per cent of the summer season extending from May to September. If the repeater spacings shown were used, the total static noise in the top channel at the end of a circuit with 20 repeaters would be 20 db above reference noise at the − 9 db level. However, other factors such as ice may require the use of shorter spacings.

Transposition System	Wire Spacing (Inches)	Noise (db) *	Repeater Spacing in Miles—128-Mil Wire
Alternate Arm	12	+ 10	67
K-8-2	8	+ 5	82
J-1	6	− 2	103

* Above reference noise, 10^{-12} watt at 1000 cycles.

LINE IMPEDANCE

As mentioned previously in the discussion of crosstalk, it is important that the line impedances be matched closely and large irregularities be avoided. Because of the different wire sizes and pair spacings, a wide range of open-wire line impedances may be encountered. Novel construction arrangements and the development of new lead-in circuits have made it possible to secure a reflection coefficient of about five per cent at the junction between the open-wire pair and the toll entrance and office equipment at the highest transmitted frequency.

The transposition arrangement and wire spacing of a pair affect the smoothness of its impedance because they affect the reactions between circuits which cause absorption effects. The marked improvement which can be obtained by proper design is illustrated by comparison of Curves A and B of Fig. 11. Curve A shows the impedance of a

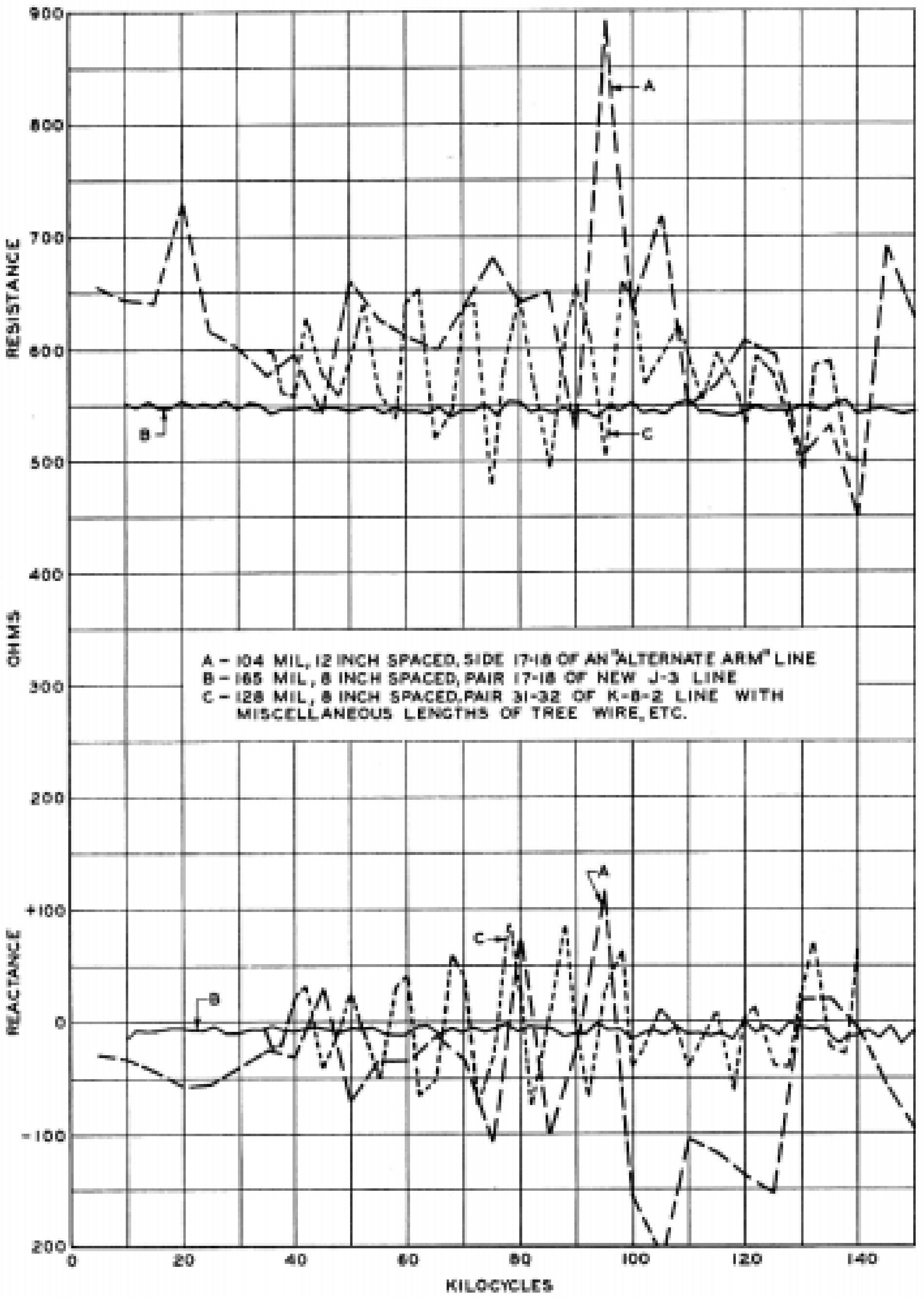


Fig. 11—Impedances of open-wire pairs of different types.

12-inch spaced side circuit on an Alternate Arm line. This particular circuit was one intended for use at frequencies not above 10 kilocycles. In striking contrast Curve B shows the comparatively smooth impedance of an 8-inch spaced non-phantomed pair on a new line transposed in accordance with the J-3 system.

"Tree" wire, a special line wire with abrasion-resistant insulation, has been used on open-wire lines for many years in places where the lines were exposed to tree branches. During line tests in Florida, another use for tree wire was found where the open-wire line, along a causeway or bridge, is subject to fouling by fishing tackle. Curve C of Fig. 11 shows what a half-mile or so of this tree wire, supplemented by several sections of 165-mil wire at railroad and power-line crossings, can do to the impedance of a 128-mil pair. To reduce the irregularities a new type of insulated line wire of smaller diameter and with thinner insulation was developed. This wire has about the same impedance characteristic as the line wire.

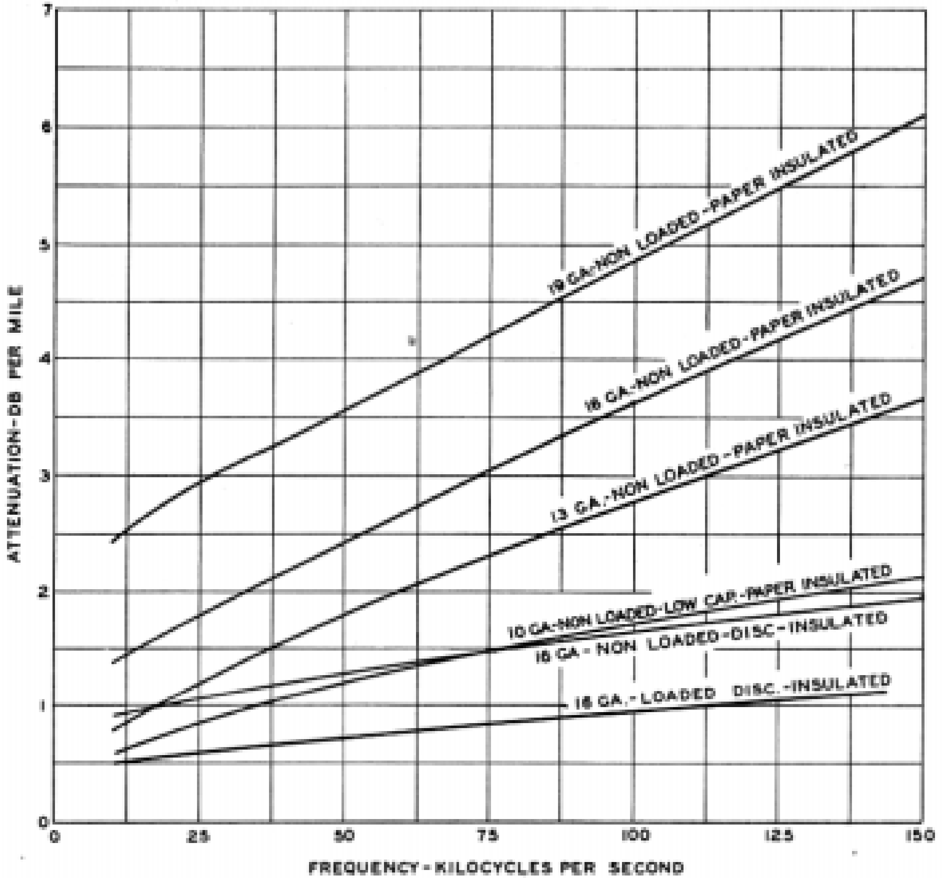


Fig. 12—Attenuation of toll entrance cable pairs.

Intermediate Cable Treatment

When open-wire lines have to be placed underground to pass through towns or to cross natural barriers such as rivers which cannot be spanned economically with open wire, cable is used. In the past, the circuits in such cables were frequently loaded to reduce their attenuation and to match the impedance of the open-wire circuits in order to avoid reflection effects and degradation of voice-frequency repeater balance. To load paper-insulated cable pairs for frequencies up to 150 kilocycles would require exceedingly short loading spacing, of the order of 200 feet, which would be expensive and in many cases impractical with existing manhole locations. An alternative, the use of a transformer to match the open wire and cable impedances, was rejected as it was found impractical to design a transformer which would be adequate over the entire frequency range.

To overcome these difficulties, a new low-capacitance type of cable was developed which could be loaded to match the open-wire impedance with coil spacings about the same as those previously used. Loading coils of different sizes were developed to provide for loading to the different impedances of the open-wire circuits.

The new cable employs 16-gauge conductors in a spiral-four arrangement, supported by hard rubber disc spacers about 0.6 inch in diameter. These are surrounded by copper and iron tapes for shielding and strengthening purposes. The units so formed may be assembled either in single units in a lead sheath as for lead-in purposes, or in multiple units, up to a maximum of seven for full-sized cable, within the same lead sheath. For duct runs or submarine cables, the multiple assembly is usually employed, and, in the latter case, with outside armoring and jute protection. If the submarine span is more than about 600 feet, intermediate submarine loading is employed.

As an alternative, it sometimes happens that where a long intermediate cable is involved, an auxiliary type J repeater station can be placed conveniently at one end of this cable. In this case, the filter hut described in the discussion of toll entrance arrangements in the next section may be used at the end of the cable opposite the repeater station and the cable treated as a toll entrance cable for the auxiliary office. A further alternative is to provide filter huts at the two ends of a non-loaded intermediate cable. However, if the cable is short, the new disc-insulated cable with loading is to be preferred.

Previous practice at the ends of open-wire lines has been to use paired bridle wire with weather-proof insulation and usually of smaller gauge than the line wire to connect the open-wire pairs to cable terminals mounted on the pole. Other pairs of bridle wire were connected between the open wires and protectors. Because of the much more severe reflection requirements at the higher frequencies of the type J system, these arrangements were no longer satisfactory. The characteristic impedance of bridle wire is roughly one-fifth of that of the open-wire circuit and it has been necessary to avoid the use of even several feet of it between the open-wire and the cable terminal or protectors. To accomplish this, separate terminals for each disc-insulated unit are mounted on the crossarm near the open-wire pairs to which they connect. Four insulated wires from each terminal go by the shortest feasible route to the longitudinal choke coils and protectors and thence to the open-wire pairs.

Toll Entrance Arrangements

The new disc-insulated cable used for intermediate cables was also suited for lead-in or toll entrance cables.

When an auxiliary station is established at a point along an open-wire line where there has not previously been an office, it is usually located close to the line so that the lengths of lead-in cable required are comparatively short. Lengths of this cable up to about 175 feet can be loaded to open-wire impedances with adjustable loading units in the repeater station. For longer lead-in cables up to 300 feet, supplementary loading may be mounted directly on the pole at the cable terminals.

When an auxiliary repeater station is not close to the open-wire line, or at main repeater stations which are frequently in towns and separated from the open-wire line by greater lengths of toll entrance cable, it is still possible to use the loaded disc-insulated cable. Because of the cost of this cable and its loading, however, it has sometimes been found more economical to build a hut near the open-wire terminal pole and to separate the type J from the type C and lower frequency facilities at that point by means of filters. The connection from the open-wire line to the hut is provided by what is usually a short length of loaded disc-insulated cable. From that point, the type J frequencies are led into the toll office over non-loaded paper-insulated pairs while the C and lower frequency facilities are brought in over the existing pairs, usually loaded. By thus limiting the frequencies transmitted over the non-loaded cable pairs to the J range, it becomes practical to design transformers for suitable impedance matching.

The line filter sets located in the hut are designed for a nominal impedance of 560 ohms which is a compromise for the range of impedances normally found with different wire sizes and spacings. An accurate match with the line is obtained with a building-out network which is adjusted at the time of installation to fit the particular open-wire pair involved. On the office side of this line filter set a transformer provides for stepping down the impedance from 560 ohms to the impedance of the toll entrance cable, which is usually about 125 ohms. Adjustment of this impedance over the necessary range to match impedances of particular cable pairs is provided by means of taps on the transformer. At the office another transformer similarly tapped is employed to match the toll entrance cable pair impedance to that of the office wiring.

Fig. 12 shows the losses of the commonly used 19-, 16- and 13-gauge paper-insulated toll entrance cable, a new 10-gauge low capacity cable, and the new disc-insulated cable. Because of the high losses of the smaller gauge pairs, it is sometimes economical to place new 10-gauge cable to save repeater costs.

For the office wiring of the J system a rubber-covered shielded pair is used to provide the desired flexibility and freedom from capacitance variation due to humidity changes. Its impedance at 140 kilocycles is approximately 125 ohms. The repeater and terminal high frequency impedances are designed to match this impedance very closely.

Fig. 13 illustrates the arrangement of the toll entrance equipment involved in matching the line impedance to that of the equipment with a minimum of reflection. The terminal is illustrated to the left. The high frequency line passes to the line filter set which is here shown as located in a filter hut. There it is joined by the type C and lower frequency circuits and passes through the lead-in cable and protective arrangements on the terminal pole.

Proceeding toward the right in the figure, the arrangement at an auxiliary repeater station is shown. In this case the type J frequencies are amplified in the repeater, but the type C and lower frequencies are by-passed through filters which suppress longitudinal and metallic transmission above 30 kilocycles. At the right is shown a combined type J and type C main repeater office.

Satisfactory crosstalk between pairs in entrance and intermediate cables carrying J systems is effected through special selection methods and the application of balancing condensers.

REFLECTION COEFFICIENTS

The success of the various measures taken to insure good impedance matching is shown by the curves of Fig. 14, which are of reflection coefficients measured at an auxiliary repeater station. Curve A, the solid line, gives the coefficient between the open-wire pair and the lead-in cable at the terminal pole. The smaller variations are due partly to irregularities of the open-wire line and, at the lower frequencies, partly to the test terminations at the distant end. The contribution of the cable loading and office equipment is indicated by the dash-line curve

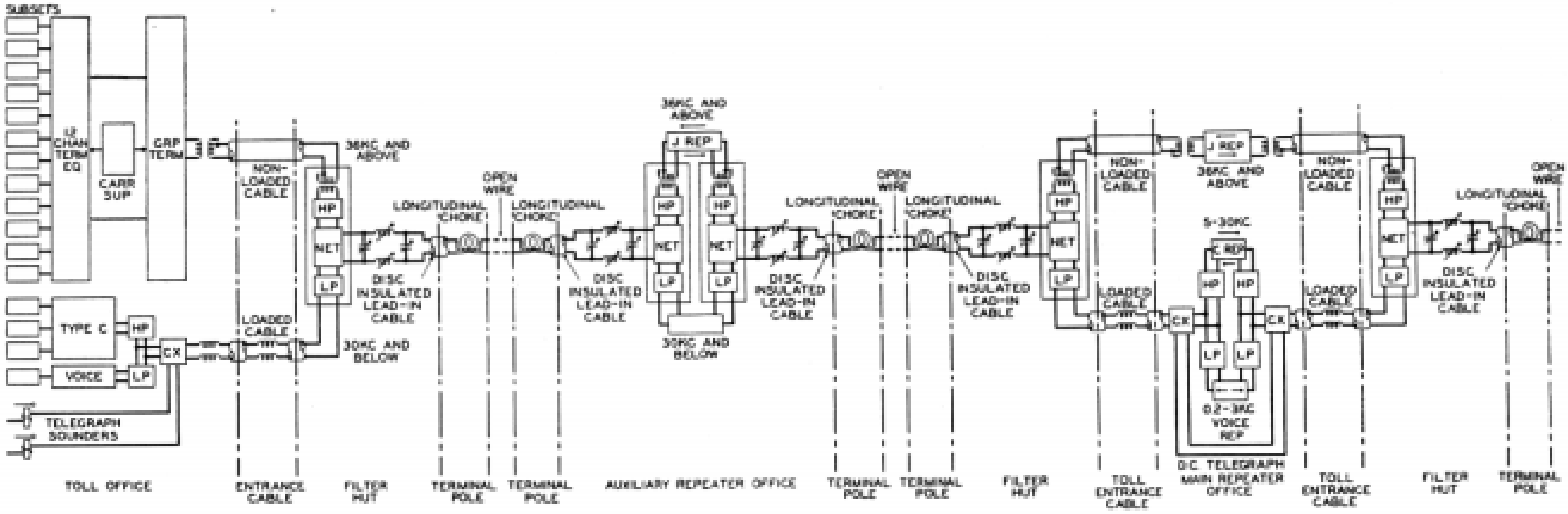


Fig. 13—Toll entrance arrangements at J terminal and repeater offices.