Oct. 30, 1934. H. W. DUDLEY 1,978,419

TRANSMISSION SYSTEM

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FIG. 1A

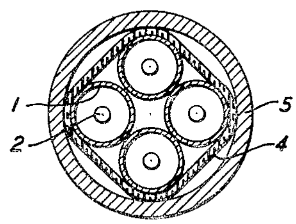


FIG. 1B

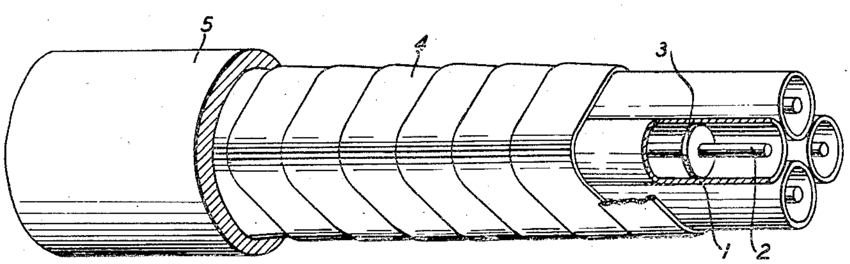
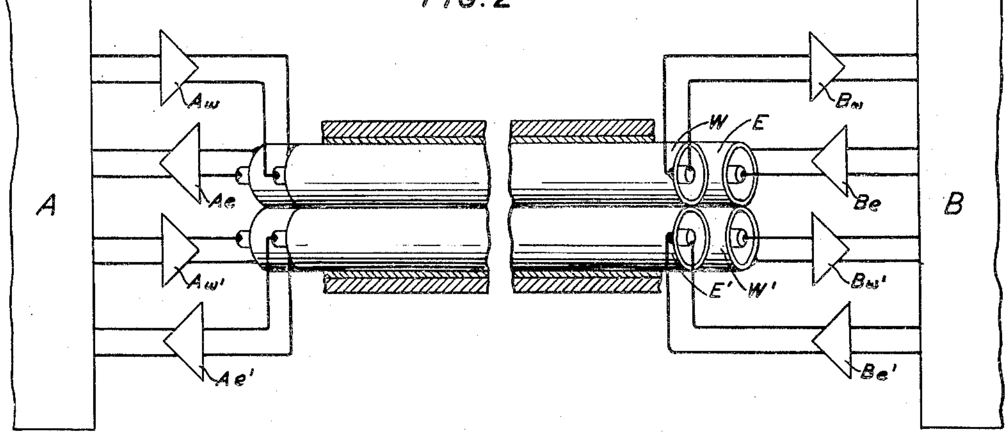


FIG. 2



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TRANSMISSION SYSTEM

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FIG. 3A

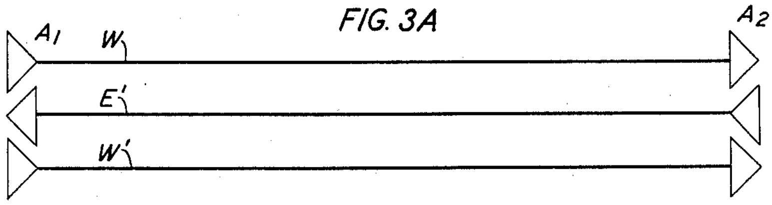

FIG. 3B

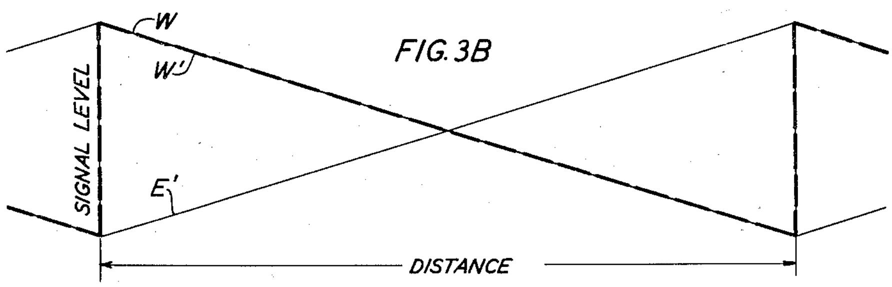

FIG. 3C

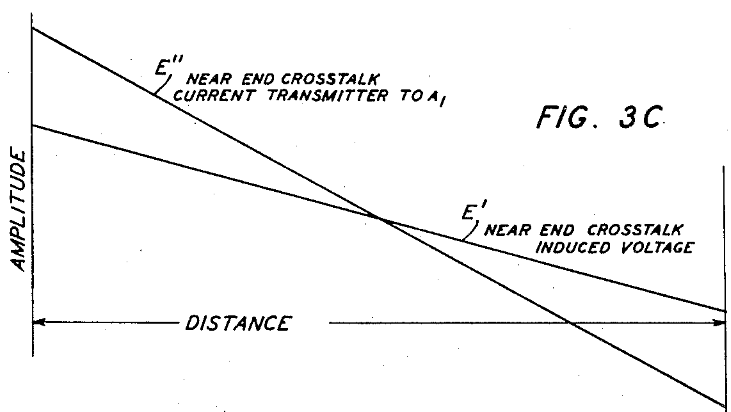

FIG. 3D

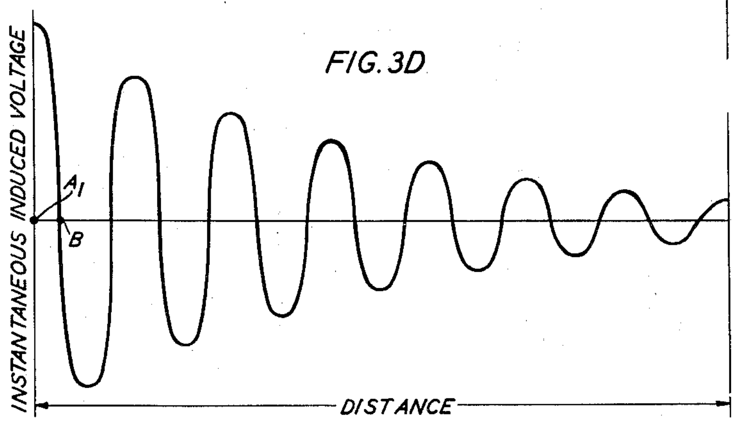

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FIG. 7

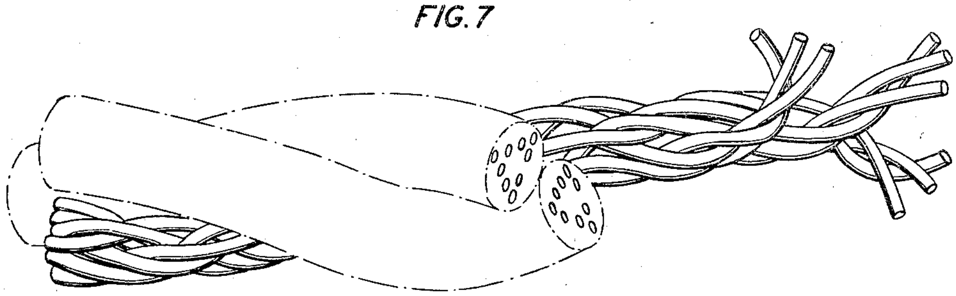


FIG. 5

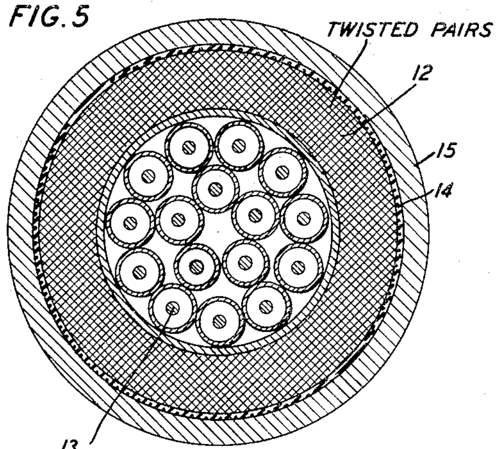


FIG. 6

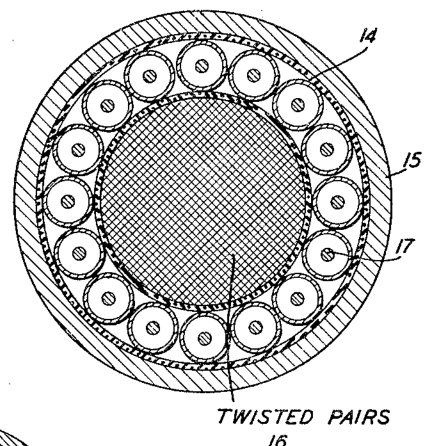


FIG. 4A

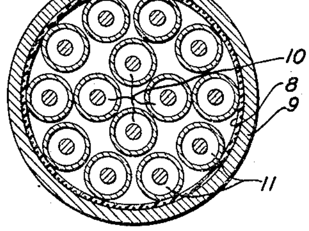
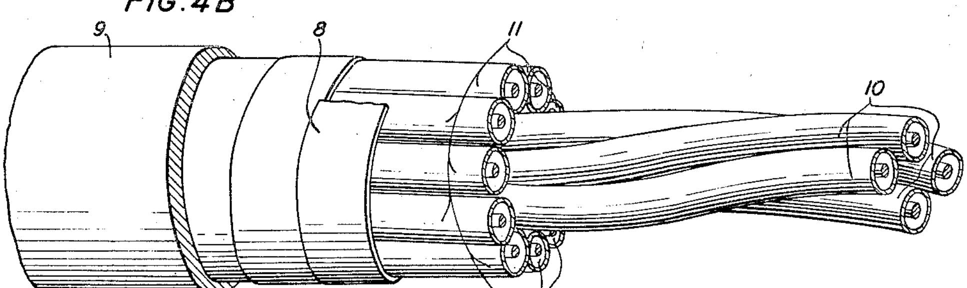


FIG. 4B



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TRANSMISSION SYSTEM

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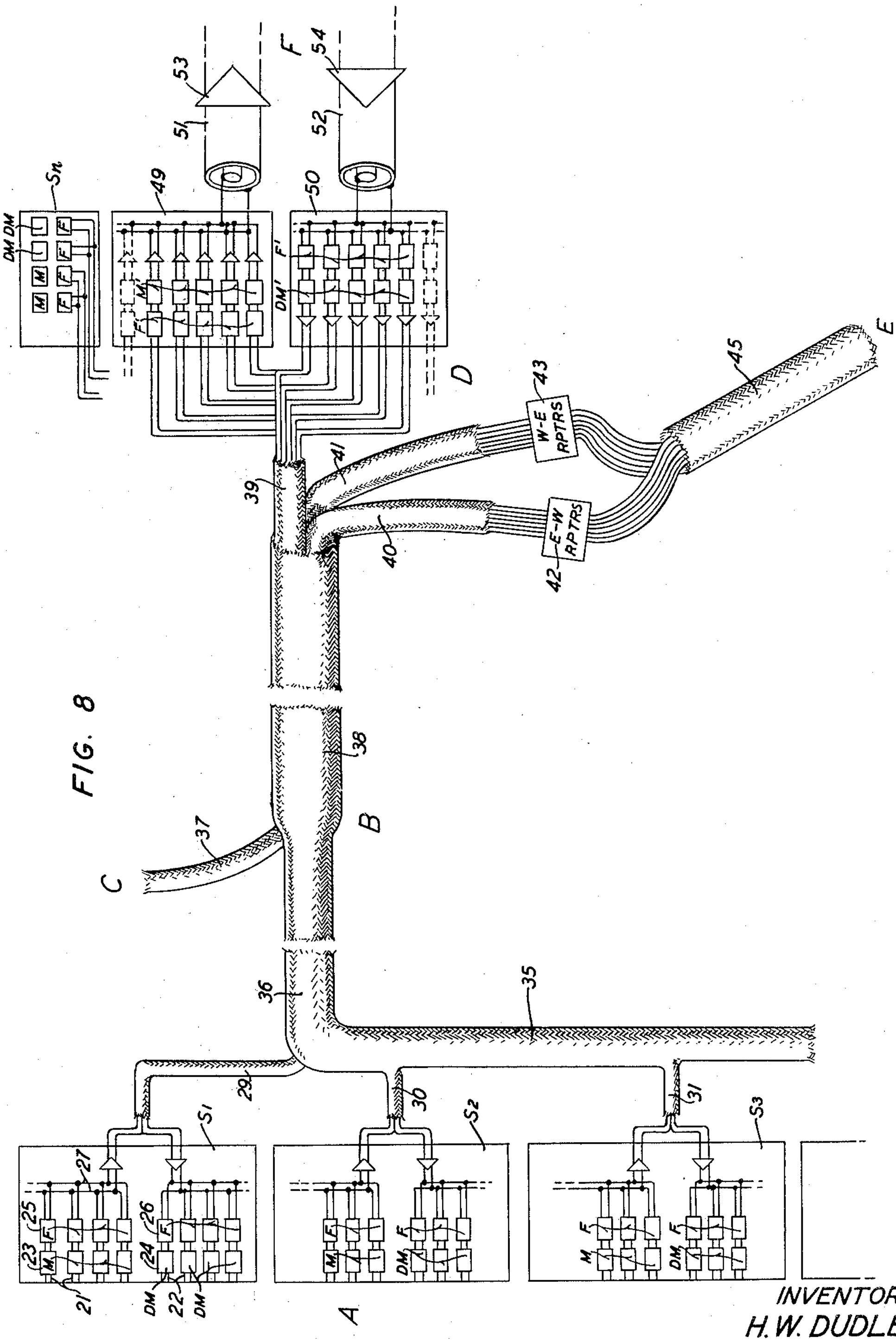
FIG. 8



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Patented Oct. 30, 1934

1,978,419

UNITED STATES PATENT OFFICE

1,978,419

TRANSMISSION SYSTEM

Homer W. Dudley, East Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 19, 1932, Serial No. 606,135

6 Claims. (Cl. 178—44)

This invention relates to conducting systems for the transmission of intelligence and more particularly to cable systems adapted for carrier wave transmission.

One of the chief obstacles met in carrier communication practice is "cross-talk" between circuits caused by the induction of energy from one signaling line to a parallel one. The higher the frequency, the more efficient becomes this transfer of energy, and an upper limit is imposed on the frequency range that may practically be used for signaling purposes. To reduce cross-talk in open wire systems, the several carrier circuits are ordinarily widely separated and transposition of the conductors is restorted to; but the utility of this remedy ceases, from a practical standpoint, at a frequency of the order of forty thousand cycles per second.

Where carrier channels are superposed on different pairs of conductors in a cable, cross-talk becomes an even more difficult problem. It is partially solved by twisting the conductors of each pair together, by shielding arrangements, and by proper disposition of the conductor pairs within the cable. If one conductor pair of the cable be used for one direction of transmission and another pair for the opposite direction, signals of high energy leaving a terminal station or repeater over one path are induced into circuits used for the opposite direction of transmission, where the signals, just arriving at the repeater or terminal station, are at a very low level and easily masked by interference. This "near-end cross-talk", as it is termed, is ordinarily so severe that conductor pairs of transmitting signals in opposite directions in the same frequency range must be placed in separate cables. "Far-end cross-talk", which is caused by induction from one circuit to another transmitting signals in the same direction, is present but is not a limiting factor. Obviously, it would be more desirable to have a given number of conductors all in one cable rather than divided between two. Less protective and insulating material would be required, less conduit space occupied, and the manufacturing and laying expenses would be appreciably reduced.

A primary object of the present invention is to provide a signaling system wherein carrier frequency signals in the same frequency range may be transmitted in opposite directions over pairs contained within a single cable. In another aspect, an object of the invention is to realize to the fullest extent the possibilites of a multi-circuit coaxial conductor cable such as disclosed in my application for Letters Patent bearing Serial No. 487,153, filed October 8, 1930.

The present invention follows from the discovery by applicant that in a signaling cable comprising a number of pairs of coaxial conductors, as disclosed, for example, in the application for patent referred to above, induced voltages tending to produce near-end cross-talk are inherently neutralized to a large degree. The neutralizing effect is so great in fact that near-end cross-talk is less serious than far-end cross-talk, and the levels of both are low enough that conductor pairs within the same cable may be used indiscriminately for transmitting signals in the same frequency ranges in either the same or opposite directions. The invention herein claimed lies, therefore, not so much in the cable itself as in its combination with suitable signaling apparatus. Its nature will appear more fully in the discussion and detailed description of preferred embodiments that follow. Reference will be made to the accompanying drawings, in which:

Figs. 1A, 1B, 4A, 4B, 5 and 6 show the structure of cables adapted for use in applicant's transmission system;

Fig. 2 represents diagrammatically the cable of Fig. 1 and the circuit with which it may be used in accordance with the present invention;

Figs. 3A to 3D illustrate the effect of cross-talk in applicant's system and in systems known heretofore;

Fig. 7 represents one preferred form which the central conductor may take; and

Fig. 8 shows a carrier wave transmission system embodying the present invention.

Referring now to Figs. 1A and 1B, there is shown a cable in accordance with the present invention which comprises four pairs of coaxial conductors enclosed within a tubular lead sheath 5. Each coaxial pair may comprise a thin tubular outer conductor 1 preferably of copper, and a central return conductor 2 also of copper. The latter may be a solid wire as shown, or alternatively, a stranded wire, a small tube or other suitable structure. The outer conductor may be a drawn copper tube as shown, or formed of sheet copper or stranded wire, or of any other form that will provide a substantially tubular conducting path and a fair degree of mechanical flexibility. The diameter of the outer conductor may be of the order of a quarter or half inch.

Since the frequency of the signals applied to the conductors may be as high as a million cycles per second, it is especially important that as little solid material as possible be placed in the region between the conductors of each pair. Preferably, the dielectric is gaseous or chiefly so. Beads or washers 3 of insulating material are strung along the central conductor at intervals of the order of an inch, or as required for mechanical support, to prevent contact between inner and outer conductors. The dielectric constant and conductivity of this material should be as low as possible to minimize losses.

No insulation need be used between the outer conductors of the several coaxial pairs when the latter are assembled as a cable; the outer conductors are normally operated at ground potential. In fact, as will appear hereinafter, a certain advantage inheres if the conductors are in good electrical contact. Accordingly, a continuous serving of metal or fiber tape 4 is preferably applied to the four conductors to bind them together. A mechanically improved structure is obtained if a twist is imparted to the assembled conductors before they are bound together. A twist of roughly one turn in three feet is satisfactory. The spaces between tapes and conductors may or may not be filled out with suitable packing material to provide a cylindrical exterior. In either case, the assembly is or may be provided with a lead sheath 5 applied by extrusion.

In Fig. 2 the essential features of the present invention are illustrated schematically. A and B represent the signaling circuits at the terminals of a carrier wave communication system using a frequency range of perhaps fifty to five hundred kilocycles per second. Connecting them is a four-pair cable of the type shown in Fig. 1. Pairs W and W′, which are preferably not adjacent to each other in the cable, transmit carrier wave signals in the same frequency band in the W—E direction. The other two pairs, E and E′, using the same respective frequency ranges, provide the return or E—W carrier channels for pairs W and W′ respectively. The directions of transmission are indicated on the drawings by the facings of the several terminal amplifiers A_w, A_e, B_w, B_e, etc.

The nature of the cross-talk action occurring in the circuit of Fig. 2 will be described with reference to Figs. 3A to 3D. Consider as a typical case the effect on circuits E′ and W′ of signals in circuit W of the cable. Induction into the return circuit E need not be considered, since the power transferred acts as an echo and the effect produced is not at all serious once the requirements for cross-talk have been met. In Fig. 3A the three parallel circuits E′, W′, and W the disturbing one, are represented graphically. A_1 and A_2 represent repeaters, which may be spaced 25 or 50 miles apart or at some other convenient spacing dictated by the over-all economy of the system. The signal power in line W, logarithmically expressed, and that in line W′ also, decreases approximately uniformly with the distance from the repeater A_1; that in line E′ decreases uniformly with the distance from repeater A_2. The relative signal levels are shown in Fig. 3B plotted against distance. The disturbing power induced at a particular point in adjacent lines varies as the signal level at the corresponding point of the disturbing line. The effect of an induced voltage depends, however, not alone on its magnitude but also on what part of the circuit it arises in. A voltage induced from line W to line W′ near repeater A_1, for example, will have less effect at repeater A_2 than an equal voltage induced near the latter repeater, since in the former case the induced wave is attenuated by the line before it reaches that repeater. The effectiveness of an induced voltage in producing cross-talk may be shown graphically by comparing it with the level of signals at that point in the distributed line where it is created. Considering far-end cross-talk, i. e., induction from line W to line W′, this ratio of induced voltage to signal level is seen to be constant at all points of the line. In other words, then, induction between lines is no more serious, as regards far-end cross-talk, at one point of the line than at another.

Where near-end cross-talk is concerned, however, conditions are entirely different. From Fig. 3B it is seen that the signal level in the disturbing line W near repeater A_2 is small compared with the signal level in the disturbed line E′, and that cross-talk voltage induced from W to E′ at this point can not be serious. Near repeater A_1, the relative levels are reversed and a high cross-talk voltage is superposed on weak signal currents. Most of the near-end cross-talk arises, therefore, in this section of the line. Curve E′ of Fig. 3C represents graphically the variation along the line of the induced voltage producing near-end cross-talk, assuming the same mutual inductance per unit length. While this induced voltage drops off as we go away from A_1, the signal level in the disturbed circuit at the same time increases, with the net result that the disturbing effect decreases twice as rapidly as E′ in Fig. 3C This effect is indicated by the line E″ of the latter figure.

As to the general nature of the cross-talk action set forth in the foregoing paragraph, twisted pair lines and coaxial conductor lines are alike. Several essential differences are discovered, however, on closer examination. In the first place, cross-talk between twisted pair circuits increases with freqency, while for coaxial conductor lines because of a decreasing shielding effect with decreasing frequency, it is the low frequencies that are most troublesome. In a twisted pair cable, further, the amptitude and the polarity of the voltage induced from one pair to another varies in a more or less random manner along the cable since the coupling between circuits varies because of the twist of the conducting pair. The total effective induced voltage in such a case varies approximately as the square root of the length of the cable in accordance with the theory of probability. Where coaxial conductors are used, on the other hand, the coupling between ciruits is the same at all points and the total effective induced voltage increases as the first power of the length of the repeater section. Over-all cross-talk in both cases should be at least 60 decibels below the level of signals. Inasmuch as coaxial conductor lines are adapted for long distance transmission, the cross-talk arising in each repeater section must be kept at a very low level.

A consideration of near-end cross-talk in a coaxial conductor cable system is unique in that it must take into account variations in phase of the signals along the line. Assuming a velocity of propagation of 180,000 miles per second, the length of a 50-kilocycle signal wave is 3.6 miles, which is small compared with the length of the repeater section. The instantaneous induced voltage might be as shown by the attenuated sine wave of Fig. 3D. Here the voltage wave is shown at the instant when the voltage at A_1 is a maximum. The current transmitted to A_1 by the voltage induced in the line in the immediate vicinity of A_1, is therefore at a maximum at this instant. Some dstance from A_1, at point B, the induced voltage leads the reference vector, i. e., the voltage induced at A_1, by one-quarter cycle. The current set up by the voltage induced at B arrives one-quarter cycle later at A_1, delayed by virtue of its transmission over one-quarter wavelength of line. The voltage now induced at A_1 lags by one-quarter cycle the reference wave and by one-half cycle the current wave arriving at A_1 from B. The total phase difference between the current set up at A_1 and that arriving there from B is, therefore, one hundred eighty degrees. In other words, these cross-talk currents tend to annul each other instead of to reinforce each other. Reduction in near-end cross-talk due to phase shift is effective only when the induced voltages at different points of the line bear the same phase relation to the inducing voltage, a condition that obtains in the case of coaxial conductor lines.

Under some circumstances, cross-talk can be reduced by electrically insulating the coaxial conductor pairs from each other. The advantage may be material, but only where short lengths of cable are involved, as ten to three hundred feet. With the conductors thus insulated cross-talk varies approximately as the square of the length of the cable, and for lengths greater than roughly two miles greater cross-talk may result than with uninsulated conductors. Where the interval between repeaters is to be of the order of twenty-five miles, the several coaxial conductor pairs of the cable are preferably bound together in good electrical contact as hereinbefore described in connection with Fig. 1.

While the present invention has been thus far described with reference to a four-pair cable, it is obvious, of course, that this has been done only for purposes of illustration. Generally, the cable will comprise a much larger number of pairs. In Figs. 4A and 4B is shown a typical multi-layer cable in accordance with the present invention. The central layer comprises four pairs 10 arranged as at the corners of a square, and a second layer comprising ten pairs 11 arranged roughly in the form of a circle about the central layer. A binding of tape 8 and a lead sheath 9 may enclose the assemblage. The outer conductor of each pair may be, for example, 0.3 inch in diameter and 0.020 inch thick, and the lead sheath 0.100 inch thick. The outer diameter of the sheath will be somewhat less than two inches. Over the lead sheath may be placed a bedding of jute and armoring material. The exact nature of the covering over the assemblage of conductors will depend on the environment in which the cable is to be used, as the cable may be laid for example, in a conduit, embedded in soil, or hung on a line of poles. In some cases an extra waterproof cover may be extruded over the assemblage or over the individual outer conductors to keep moisture and dirt out of the space between the central and return conductors. This feature may be necessary where the outer conductors are braided or constructed in any other manner that would permit moisture and dirt to penetrate.

Additional layers of conductor pairs may be provided. Preferably, successive layers are given opposite directions of lay both to improve the mechanical qualities of the cable and to reduce cross-talk. A lay of approximately one turn in three feet is suitable for the particular cable herein described and it may be stated as a general rule that the length of lay should be large compared with the circumference of the cable.

In arranging the E—W and W—E pairs in the cable it is desirable to keep those carrying current in the same direction separated as much as possible. As to the central layer, the arrangement shown in Fig. 1 may be used in the cable of Figs. 4A and 4B. In the next layer, and in any additional layers oppositely directed circuits are preferably alternated with each other. At intervals along the cable the conductor pairs may be rearranged or transposed so that no pair is subjected to more cross-talk than another.

Another type of cable is shown in Fig. 5. In this case only the central portion of the space within the sheath is occupied by coaxial conductor pairs 13. One or more pairs of coaxial conductor circuits may be thus placed. The remainder of the space is filled with twisted pair circuits 12, which may be arranged as quads or in any other suitable manner. In the cable shown in Fig. 6, the coaxial pairs 17 are arranged in a circle just within the lead sheath 15, and the central region is filled with quads, or twisted pairs 16. With both of these compound cables, it is possible to branch off one, two or more low frequency circuits wherever required, whereas it may not be economical to branch off a coaxial pair unless the number of channels needed is of the order of a hundred.

Any of the cables herein described may be used for the transmission of television signals, carrier wave or otherwise. Television channels are less affected by noise and cross-talk than are telephone channels. Accordingly the frequency range above the useful telephone channel range may economically be used for television transmission. Induction from one television circuit to another results in distortion of the television images. In a sense any such disturbance may be termed "cross-talk".

In the design of a coaxial conductor system the construction of the central conductor merits special attention. Aside from the absolute diameters of the conductors comprising a pair, the effective resistance of the central conductor is the chief factor determining the attenuation of the system. Where a solid conductor is used, the alternating current resistance may be much greater than the resistance to direct current because of skin effect. As noted hereinbefore the central conductor may advantageously in many cases comprise a number of small strands of fine insulated copper wire so braided or twisted together as to provide a uniform distribution of current throughout the cross-section of the conductor.

The size of strand to be used depends on the frequency which the cable is to transmit. The higher the frequency, the smaller must be the strands to avoid skin and proximity effects within the individual strands. With small strands, however, a smaller proportion of the cross-section of the conductor is occupied by conducting material and more by air and insulating material. Another limitation is in the difficulty of manufacturing and handling strands much smaller than No. 40 B. & S. gauge. In any particular case a compromise between the several factors involved must be reached.

A simple method of stranding would be to divide all the strands into three or four bunches, twist each bunch separately and then twist the several bunches together. This would not be very effective, however, because many strands near the center of the bunches would tend to remain there and the results obtained would be considerably poorer than is theoretically possible.

Multiple stranding, such as indicated in Fig. 7, is to be preferred. The total number of strands is divided in groups of from two to six, and each group is twisted; for purposes of illustration, assume there are three strands per group. The twisted groups in turn are divided into other groups of from two to six; or in the case assumed, three, and twisted to form nine "ropes". The ropes, in turn, may be twisted together in groups, and the stranding operation thus repeated as many times as necessary. Where groups of three are twisted together, six stranding operations result in a cable comprising 729 strands. For frequencies of the order of five hundred kilocycles per second this number is more than sufficient.

The pitch used in the first twisting operation may be of the order of a quarter inch, although this figure is subject to wide variations. By properly adjusting the pitch and direction of succeeding operations, a fairly smooth cylindrical cable can be obtained.

A stranding system that yields uniform current distribution is not always to be preferred. Current passing through the interior of a conductor tends to repel currents in the outer strands and the crowding of the current in the latter that results increases the effective resistance. To diminish this effect a construction may be adopted such that the current density decreases as the center of the conductor is approached. The effect may be achieved, for example, by weaving the strands so that the distance between them increases toward the center of a conductor. Insulating material may or may not be used to fill the space between strands. Another possibility is to arrange the strands so that they travel more nearly longitudinally at the outside of the conductor, and more nearly circumferentially or radially toward the center. Approaching the extreme case, the interior of a conductor may be hollow, the strands being woven in re-entrant manner to form a tubular structure. A core of string, cord, or other suitable material may be inserted. Another method of obtaining a varying current density is to use poor insulation between strands to encourage the leaking off of current when the strands are near the center of the conductor. Alternatively, the leakage of current may be induced by using very long stranding pitches so that a strand stays near the center of the conductor for a considerable distance.

Fig. 8 shows a typical signaling system embodying the present invention. At New York or some other city A terminating an extensive communication system are located the carrier wave signaling circuits there indicated on the drawings. Similar circuits at various suburban points B and C and at a nearby city D, such as Morristown, N. J., are tied into the system by means of coaxial conductor cables of the type shown, for example, in Fig. 4A and 4B. From D cables might be extended to distant cities represented at E. Such a line or several of them might be laid between New York and Chicago, for example, with apparatus at several intermediate points for connecting in other cities as required.

Within the terminal city A may be located several stations S_1, S_2, S_3, etc., where signals in a multiplicity of voice frequency circuits, as those associated with a local telephone exchange system, are applied to respective carrier waves. The transmitting circuits at each station are represented, though incompletely, by the several telephone or other law frequency circuits 21, modulators 23 and band passing filters 25. Output signals are amplified and applied to one coaxial conductor pair of a multi-circuit cable 29, 30, 31, etc. Carrier wave signals received over another coaxial pair in the same cable are separated by band passing filters 26, and then reduced to audio frequencies in demodulators 24. Thence they are applied to the low frequency circuits 22, which as suggested, may be part of a telephone exchange system. For a more complete disclosure of the preferred forms of terminal circuits, reference may be had to applicant's copending application for patent bearing Serial No. 554,206, filed July 31, 1931. The number of conductor pairs in each of the cables 29, 30, 31, etc., is of course not limited to two, and a greater number may be used if more than approximately one hundred channels are required at any of the stations S_1, S_2, etc. In any case, several cables, 29, 30, 31, etc., which, for example, may be laid in conduits under the city streets, may branch into a single cable 35 at various points to form the complete cable 36.

Another cable 37 from various suburban points may join cable 36 to form cable 38, which leads to the nearby city D. The circuits at the suburban stations which are associated with cable 37 may be of the same type as those represented at S_1. Some of the conductor pairs in cable 37 may branch into cable 36, others into cable 38, while still others may make a T connection with through circuits between points A and D. The latter conductor pairs may then be used for connection with either A or D as changes in the distribution of traffic may require.

At D one group of conductors 39 is separated for connection into another type of transmission system, to be referred to hereinafter. The remainder continues through cable 45 to a distant city such as Philadelphia. The latter circuits are separated within the station at D into groups 40 and 41, the former carrying signals in the E—W direction and the latter in the opposite direction. Each group is associated with a suitable repeater 42, 43, which comprises individual amplifiers for the several conductor pairs. The cables employed throughout the system may be of the type described hereinbefore. Between any two points a single cable only need be used, since in accordance with the present invention, conductor pairs carrying signals in opposite directions may be included in the same cable. Where the outside diameter of such a cable would be excessive, however, the conductors may of course be separated to form two or more cables.

The conductors 39 which are separated from the rest of the conductors of cable 38 are connected with the terminal of another type of transmission system which also is represented at D. Between city D and some distant one, San Francisco, for example, several hundred circuits may be required continuously. Such being the case, a single pair of coaxial conductors of perhaps several inches outer diameter may be provided between these points, together with suitable terminal apparatus for utilizing the greater signaling frequency range thus made available. This type of system is disclosed, for example, in U. S. Patent No. 1,835,031, issued December 8, 1931 to H. A. Affel and E. I. Green and in an application filed by M. E. Strieby on May 21, 1931 bearing Serial No.

538,919, which issued as U. S. Patent 1,941,116 on December 26, 1933. This system includes modulating apparatus 49 for transferring the several 50–500-kilocycle carrier signaling bands transmitted over conductor 39 to respective positions in a frequency band that may extend from five hundred to five thousand kilocycles per second. The resultant signals are then applied to a single pair of coaxial conductors 51 for transmission to a distant city F. A similar pair of conductors 52 carries signals in the opposite direction. Signals from the latter are applied to apparatus 50 where they are first separated by filters into bands of approximately four hundred and fifty kilocycles in width and then demodulated to reduce them to 50–500-kilocycle bands. The latter are applied to individual conductor pairs in cable 39. The local telephone exchange system of city D may be connected with apparatus S_n similar to S_1, S_2, etc., and the output circuit thereof connected to either of the transmission systems converging at that city.

Each of the two systems converging at D has a field of usefulness and advantages peculiar to itself. The coaxial conductor line of large diameter may be used practically to transmit frequencies of five thousand kilocycles per second and higher, the repeaters being spaced every 25 or 50 miles or otherwise as economy dictates. A thousand or more carrier telephone channels may be carved out of the frequency range thus made available. A single amplifier at a repeater station may serve for these one thousand channels. Offsetting these economic advantages to a certain extent is the cost of the copper required for the conductors; but the system is nevertheless from both physical and economic standpoints well adapted for the transmission of signals over a distance of several hundred, or even several thousand miles. At the terminal circuits, however, difficulty and expense is involved in establishing and separating the many closely-spaced, radio frequency signaling bands. Simple band pass filtering circuits cannot be used for a number of reasons, chief among which is their lack of selectivity. Instead, multiple modulation and demodulation and successive filtering is resorted to. To separate a small number of bands, or even a single one, complex and expensive circuits of this nature are required. The system is therefore not well suited where channels are to be added to or removed from the system at frequent intervals along the line, as is contemplated in the system disclosed by applicant.

A coaxial conductor pair of small size, that is, of one quarter to one half inch outside diameter, has a useful signaling frequency range of the order of 50–500 kilocycles per second or greater. A hundred or more carrier telephone channels may be superimposed on each pair. Band passing filters using piezo-electric crystals are sufficiently selective to separate signaling bands in this frequency range, as disclosed in applicant's copending application for patent bearing Serial No. 554,206, filed July 31, 1931. Carrier channels may therefore be readily added to or removed from a pair of conductors as required. If as many as one hundred signaling channels are needed at a particular city along the route of a cable, one or more pairs of conductors may be branched from the cable to serve this point. In a system using a large coaxial conductor, on the other hand, filters, modulators, demodulators, etc., would be necessary to provide these facilities. In general, it may be said that the use of multi-circuit coaxial conductor cables in accordance with the present invention affords a highly flexible system.

In the system shown in Fig. 8, the respective conductor pairs of the cables 29, 30, etc., and 36, 37 and 38 are indicated as transmitting signals in one direction only. In some cases, however, it may be found desirable to transmit signals in both directions over a single pair of conductors, different frequency ranges being used for this purpose in a manner well known in the art. The present invention is therefore not limited to systems in which each conductor pair transmits signals in one direction exclusively, since in the case just described, transmission in the opposite directions in the same frequency ranges may still obtain.

This specification in other respects also does not attempt to describe all the modifications and applications of the present invention that will readily occur to those skilled in the art. The basic novelty of the invention is such as to include all embodiments that come within the scope and spirit of the appended claims.

What is claimed is:

1. In a signaling system, a cable comprising a plurality of pairs of coaxial conductors, and means for transmitting carrier telephone signals in the same frequency ranges in opposite directions over different pairs of said conductors, said pairs being shielded from each other only by their respective outer conductors.

2. In a telephone transmission system, a cable comprising a multiplicity of pairs of conductors, means for keeping the level of near-end cross-talk occurring in said system less than that of far-end cross-talk and both insufficient to cause objectionable interference, said means consisting of one conductor of each of said pairs, said conductor being hollow and arranged with the other conductor of the respective pair within it, and means for transmitting signals in the same carrier frequency ranges in opposite directions over pairs of said cable the outer conductors of which are in conductive contact.

3. In a carrier wave telephone system, a transmission medium comprising a unitary assemblage of coaxial conductor pairs, repeaters at intervals in said respective conductor pairs, and means to transmit in respectively opposite directions over different ones of said pairs signals of the same frequency, said frequency being at least several hundred thousand cycles per second and the energy level of near end cross-talk occurring in any of said pairs being at least sixty decibels less than the energy level of received signals.

4. In a signaling system, a cable comprising a multiplicity of coaxial conductor pairs, the outer conductors of said pairs being laid in substantially continuous electrical contact, and means to apply to said conductor pairs for transmission in opposite directions carrier telephone signals ranging in frequency to several hundred thousand cycles per second, the frequency ranges of said signals in different conductor pairs overlapping at least in part and their lower extremities being determined by the energy level of far-end cross-talk, said system being characterized in that near-end cross-talk is less than far-end cross-talk.

5. In a multiplex carrier wave system, a plurality of transmitters each producing a different frequency wave for transmission, a coaxial conductor connected in common to all of said transmitters, a plurality of receivers located adjacent

said transmitters and each adapted to receive a different frequency wave, a coaxial conductor connected in common to all of said receivers, said two coaxial conductors being associated as a pair, leading to a cable, said cable comprising said pair and other similar pairs of coaxial conductors connected, similarly to the first pair, to respective groups of transmitters and receivers, the frequencies used for transmitting over one coaxial conductor overlapping those used for receiving over the other coaxial conductor of the pair.

6. In a multiplex carrier wave signaling system, a first station, a second station, a multiplicity of low frequency circuits at each of said stations to be connected into said system, a cable extending between said stations, said cable comprising a plurality of pairs of coaxial conductors each a fraction of an inch in diameter and adapted to transmit with moderate attenuation waves extending in frequency to as high as several hundred thousand cycles per second, the outer conductors of said pairs being laid in substantially continuous conductive contact, a plurality of transmitters and a plurality of receivers at both of said stations, each of said transmitters and receivers including frequency translating means interconnecting a plurality of groups of said low frequency circuits with conductor pairs in said cable individual to said groups, the frequency range transmitted over one pair of said conductors overlapping the frequency range received over another pair of said conductors, other stations to be connected into said system at intermediate points of said cable, and a plurality of pairs of coaxial conductors branching from said cable and extending to said other stations.

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