Oct. 13, 1925.

L. ESPENSCHIED

1,557,037

REDUCTION OF CROSS TALK

Filed Dec. 11, 1922

2 Sheets-Sheet 1

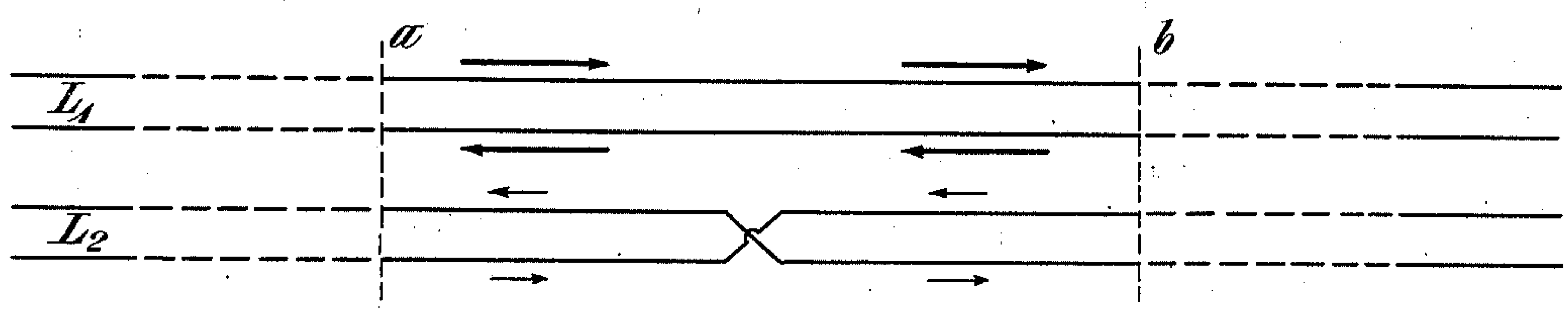

Fig. 1

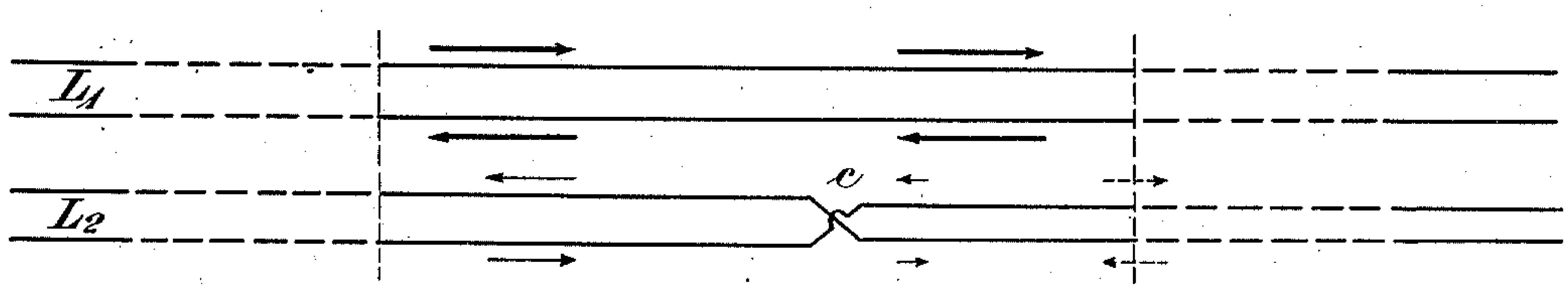

Fig. 2

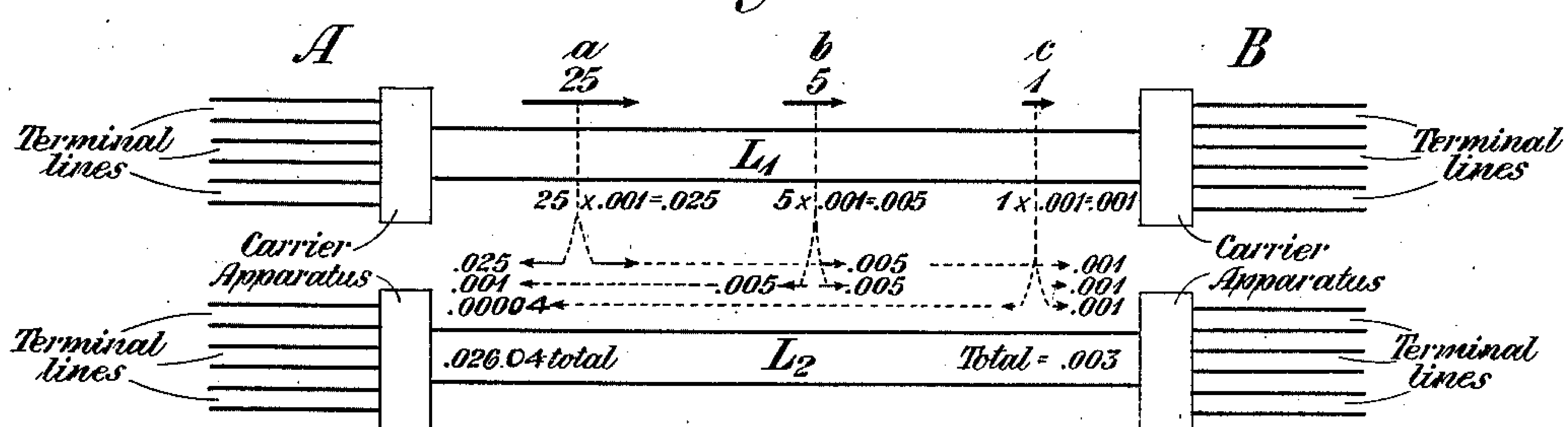

Fig. 3

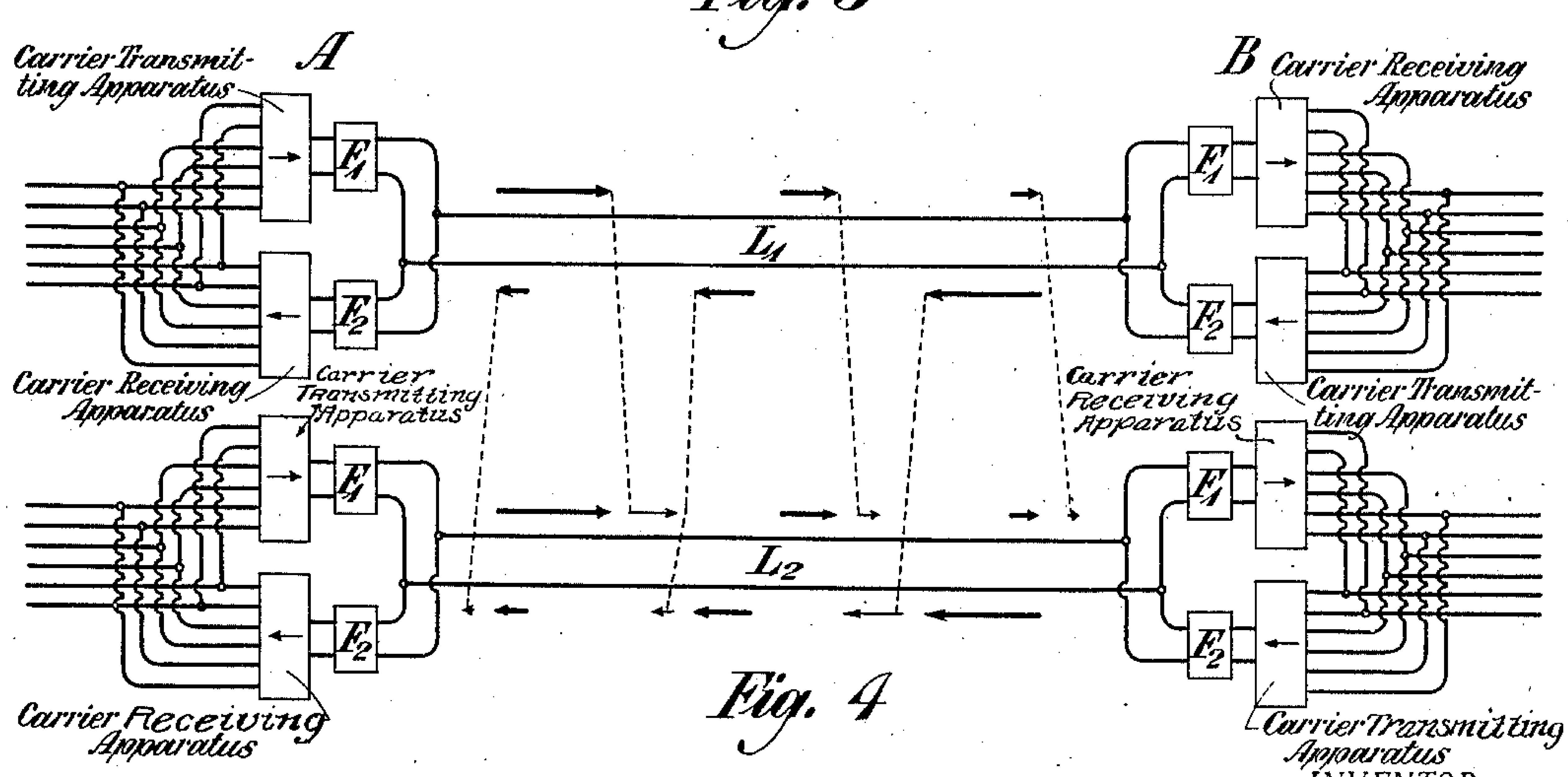

Fig. 4

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REDUCTION OF CROSS TALK

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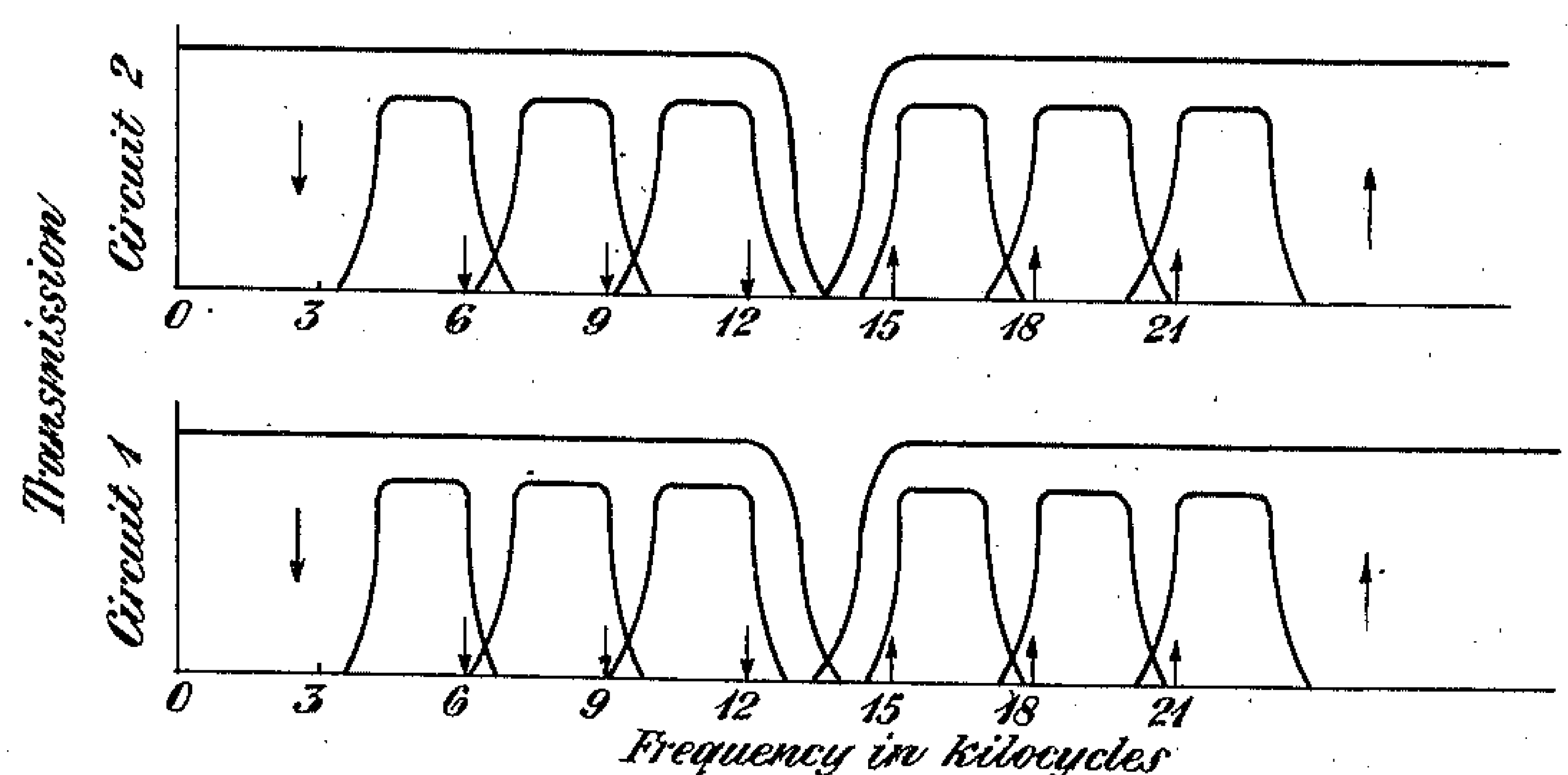

Fig. 5

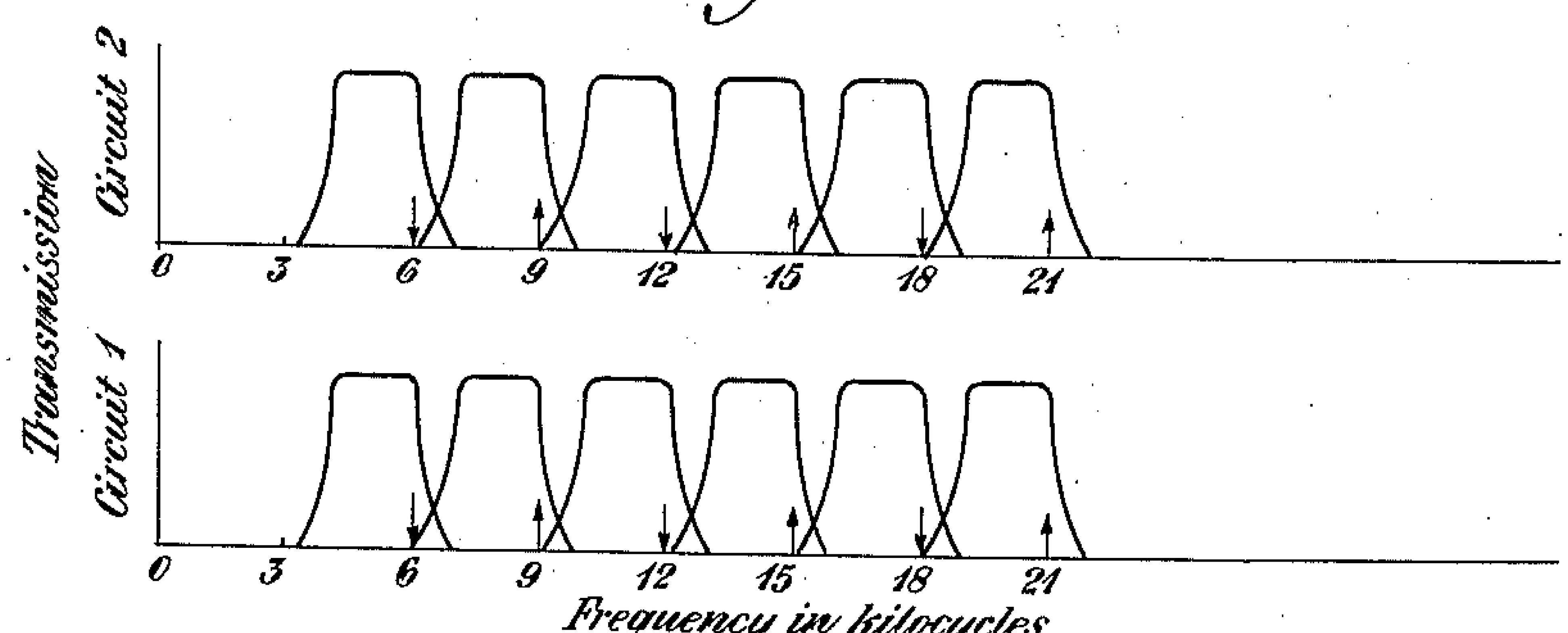

Fig. 6

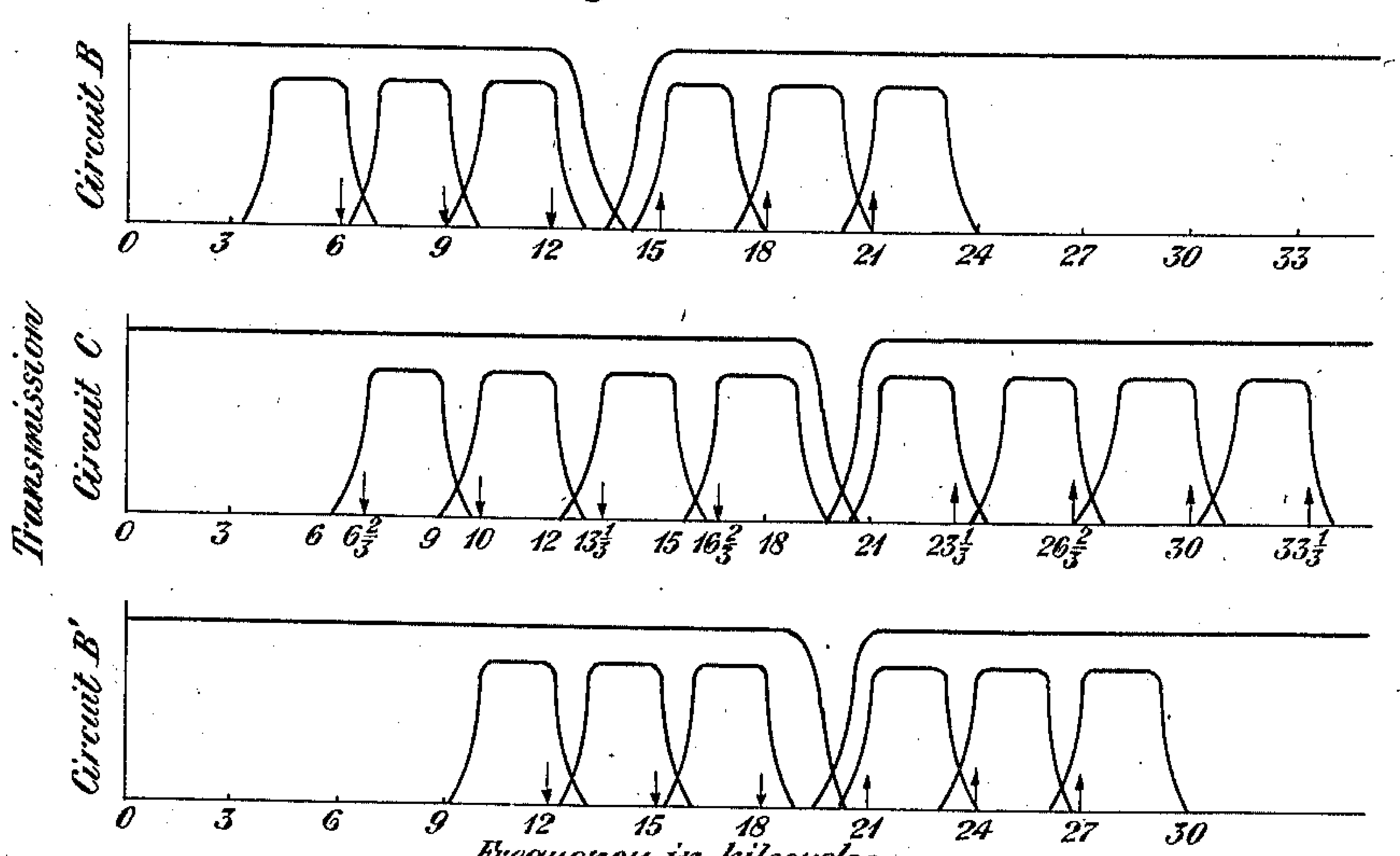

Fig. 7

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Patented Oct. 13, 1925. 1,557,037

UNITED STATES PATENT OFFICE.

LLOYD ESPENSCHIED, OF HOLLIS, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

REDUCTION OF CROSS TALK.

Application filed December 11, 1922. Serial No. 606,231.

To all whom it may concern:

Be it known that I, Lloyd Espenschied, residing at Hollis, in the county of Queens and State of New York, have invented certain Improvements in the Reduction of Cross Talk, of which the following is a specification.

This invention relates to multiplex transmission systems and more particularly to means for and methods of reducing cross-talk interference between the channels of multiplex carrier systems extending over circuits paralleling each other upon the same pole line, or the like.

It is well known that in transmission circuits of all kinds and, in particular, in telephone circuits, where the lines parallel each other, either by reason of being carried along the same pole line or by reason of being included in the same cable, the telephonic or other signals transmitted over one line will induce corresponding currents in adjacent lines, thereby producing what is known as cross-talk. This has led to the introduction in telephone circuits of what are known as transpositions at suitable intervals, the purpose of these transpositions being to balance out the induced cross-talk currents.

In the case of multiplex systems involving carrier currents upon which the telephonic or other signals are superposed, the problem of reducing cross-talk becomes one of much greater magnitude than in the case of ordinary telephonic transmission. This follows because not only are the currents induced greater in the case of the higher frequencies involved, but also the number of transpositions required is much greater and the accurate spacing of the transpositions and of the wires is much more important. To state the idea more concretely, it is a well known physical fact that the current induced between two adjacent circuits increases with the frequency of the inducing current and, consequently, for two given circuits paralleling each other the cross-talk in the second circuit, due to signaling currents in the first circuit, will be greater in the case of carrier currents than in the case of ordinary telephonic currents. It becomes at once obvious, therefore, that the means used to reduce cross-talk in the case of carrier currents must be more elaborate than in the case of ordinary telephonic transmission.

Heretofore, it has been attempted to reduce cross-talk between carrier current channels on adjacent lines by the same general method that has been employed in the case of ordinary telephone circuits, viz, by means of transpositions. In order that transpositions may be effective it is necessary that a large number of transpositions occur per wave length of the highest frequency involved; that is, if we consider a section of line extending between two transposition points, the section of line must be very short as compared with the wave length of the signaling currents employed. It follows at once that the number of transpositions required in the case of a carrier transmission circuit involving wave lengths very much shorter than those employed in ordinary telephonic practice will be quite large. Hence, to effectively transpose the lines a very considerable expense is involved.

Furthermore, the transposing of the wires, in order to be effective, must be done with a certain degree of mechanical accuracy. Unfortunately, for mechanical reasons, it is practically impossible to accurately transpose lines for frequencies of the order employed in carrier transmission. The theory of transpositions require that, in a length of line, known as a transposition section, within which all the circuits are mutually balanced the transposition points be spaced at substantially equal intervals. For obvious mechanical reasons it is necessary to make the transpositions at the cross-arms on a pole line and if the theoretical location of a transposition point does not coincide with the place at which a pole is spaced, an error will be introduced in the transposition scheme. These errors may be neglected in ordinary telephone practice, but in the case of carrier transmission, where the distance between successive transpositions is much shorter, the proportion of error is so much greater that it becomes a very serious factor. As a result, even though the required number of transpositions are actually introduced, the expected results will not be obtained in the case of carrier transmission.

In view of the imperfect results obtained by transposition and the large expense involved in this method of overcoming cross-talk in carrier circuits, it is sought by the present invention to overcome cross-talk difficulties by a simpler method and apparatus which may be employed either in conjunction with the transposition method or as a substitute therefor. An analysis of the conditions producing cross-talk shows that the greatest difficulty arises between channels transmitting in opposite directions on adjacent circuits. If we consider the conditions at the near end of an outgoing channel on one line and an incoming channel on an adjacent line it will be apparent that the outgoing currents are very large in amplitude, while the incoming currents on the adjacent line have been greatly attenuated during transmission from a distant point. Consequently, the cross-talk produced by the outgoing currents of large magnitude will have considerable magnitude as compared with the attenuated incoming currents, and in some instances it is conceivable that the cross-talk currents might be even greater in magnitude than the incoming currents received from a distant station. On the other hand, if we consider two channels transmitting in the same direction on two adjacent lines, while the cross-talk currents induced at the near end in the adjacent channels will be as large as before, their magnitude will be much smaller relative to the large signal currents transmitted in said channel. The ratio between the induced current and the transmitted current under these conditions will be substantially the same at any point along the two lines, assuming, of course, that attenuation conditions are similar in the two circuits. It follows at once that if cross-talk between channels on adjacent lines transmitting in opposite directions can be avoided, the cross-talk induced in channels transmitting in the same direction will, in some instances, be sufficiently small to be disregarded. If, however, the cross-talk is too large to be disregarded it may be reduced by a much less mechanically accurate system of transposition.

Accordingly, it is proposed by the present invention to so choose the carrier frequencies of the different channels upon two or more lines which parallel each other that not only will the bands transmitted in one direction over a given circuit lie in a different frequency range or ranges from those transmitted in the opposite direction over a given line but, in addition, all of the bands transmitted in one direction upon a given line will lie in a different frequency range or ranges from all of the bands transmitted in the opposite direction upon any of the parallel lines. By using suitable selecting means, such as band filters, it will then be possible to prevent the cross-talk currents induced by carrier currents transmitted in one direction from entering the terminal apparatus of channels transmitting in the opposite direction.

It is, of course, recognized that the idea of using different frequency ranges for transmitting in opposite directions upon a given line is old. Applicant's invention, however, goes a step further and insures that the frequency ranges employed in transmitting in one direction upon any of the parallel lines will be different from the frequency ranges employed in transmitting in the opposite direction upon all of the parallel lines. It further involves so arranging matters that any employed frequency ranges which are common to two or more parallel lines will be used for transmission in the same direction.

It by no means follows from the fact that it was heretofore the practice in some cases to separate the frequency ranges employed in transmitting in opposite directions upon a single line, that the application of this old principle of a number of parallel lines would produce the results obtained by applicant's invention. Various conditions might arise to prevent the attainment of applicant's results. If the frequency ranges employed for transmitting in opposite directions upon each of two parallel lines are segregated from each other, the systems upon the two adjacent lines might still be so arranged that the frequencies employed in the two cases would be different, so that there would be an actual overlapping in frequency between the frequency ranges employed for certain channels transmitting in opposite directions over the adjacent circuits. Furthermore, even though the systems on the two parallel lines employed identical frequency ranges and an identical arrangement of channels, so far as frequencies are concerned, the frequency bands employed for transmission from east to west upon the one line might happen to be used for transmitting from west to east upon the adjacent lines. Obviously, under this condition, the very worst cross-talk conditions would obtain. To apply applicant's invention to this situation would, therefore, involve reversing the direction of transmission upon one of the lines. As a matter of fact, before applicant's invention no carrier systems have ever been installed upon parallel lines under such circumstances as to avoid the two conditions just referred to, for the necessity of complying with these requirements was not appreciated.

The invention may now be more fully understood from the following description when read in connection with the accompanying drawing, Figures 1 and 2 of which represent the conditions obtaining where two adjacent circuits are transposed under different conditions, Fig. 3 of which illustrates the distribution of the cross-talk curents in a carrier system to which applicant's invention has not been applied, Fig. 4 of which shows the distribution of currents upon two adjacent lines to which applicant's invention has been applied, Figs. 5 and 6 of which show different methods of segregating the frequencies upon adjacent lines in accordance with applicant's invention and Fig. 7 of which compares the conditions in adjacent circuits where the frequencies are segregated in accordance with applicant's invention with the conditions obtaining when the segregation in the two circuits does not follow the principles of applicant's invention.

Before proceeding to a detailed exposition of applicant's invention, the method of overcoming cross-talk by transpositions will first be discussed. Referring to Fig. 1, let us consider two parallel circuits L_1 and L_2. Let us assume that the wave lengths employed in transmitting over these circuits are such that one transposition must occur in every section of the line having a length equivalent to that indicated between the points *a* and *b*. This transposition may be obtained by crossing the wires of the line L_2, for example, midway between the points *a* and *b*. If the current flowing over the line L_1 is of the magnitude and direction indicated by the heavy arrows adjacent the line L_1 between the points *a* and *b* then the direction and magnitude of the induced current in the line L_2 may be as represented by the arrows adjacent the conductors of the latter line. These arrows, it will be observed, are in such a direction that the induced currents oppose each other in each side of the circuit. Now, if the two half sections on each side of the transposition of the line L_2 are electrically equal, the induced currents will exactly neutralize each other and no cross-talk will result, provided, of course, that the sections are very short as compared with the wave length.

In practice, the perfect conditions illustrated in Fig. 1 cannot ordinarily be obtained. In the first place, the transposition must occur at the cross-arm and the cross-arm may not coincide with the theoretical point at which the transposition should be made. Where the wave lengths employed are long, and the interval between transposition points is large compared with the interval between adjacent poles, as in the case of ordinary telephone transmission, the shifting of the transposition from one cross-arm to the cross-arm on the next adjacent pole will be of small consequence since a relatively small difference in the lengths of the adjacent half sections of Fig. 1 would result. In the case of carrier transmission, however, where the wave lengths are not nearly so long, the interval between transposition points must be so short that the location of the transposition at the cross-arm nearest the theoretical transposition point will result in a relatively large difference in the lengths of the adjacent half section of Fig. 1. This is illustrated in the case of the circuit L_2 in Fig. 2, where the transposition point occurs at *c*, somewhat distant from the midpoint of the section.

Another factor which may cause a further variation from theoretical conditions may arise from the fact that the two parallel lines are not equally spaced upon the cross-arms at all points or a condition which is more apt to arise, the wires of the two lines sag by different amounts between the two poles. This produces a condition which is represented in the case of the line L_2 in Fig. 2, showing the two wires of the line at the right of the point *c* closer together than the corresponding wires at the left of the transposition point *c*. If, now, the heavy arrows adjacent to the line L_1 represent the magnitude and direction of the current flowing over said line in the transposition section terminating at the points *a* and *b*, the induced currents and their magnitudes may be as represented by the arrows adjacent the conductors of the circuit L_2. As indicated, the induced currents flowing over the two wires to the left of the transposition point *c* are much larger than the induced currents flowing over the two wires to the right of the point *c*. While the direction of current flow is such that the currents induced to the right of the transposition tend to neutralize the currents induced to the left of the transposition, a resultant cross-talk current will actually occur, as indicated by the dotted arrows at the point *a*.

From the above discussion, it will be obvious that the method of transposition alone will not be satisfactory for the reduction of cross-talk when applied to a multiplex carrier system. This follows from two facts; the induced currents will in any case be larger because of the higher frequencies involved and the irregularities in the wire and transposition spacing will result in the reduction of the cross-talk currents by a smaller percentage than in the case of ordinary telephone transmission.

Let us now consider the distribution of the cross-talk currents. Referring to Fig. 3, two lines L_1 and L_2 are shown which may be multiplexed for carrier transmission by means of terminal carrier apparatus, indicated schematically at A and B, so that communication may take place simultaneously in a well known manner between the stations associated with a plurality of terminal lines. Let us now consider that a current is flowing over the line L_1 and that this current has a value of 25 arbitrary units, as represented by the arrow at the point *a*, which is assumed to be adjacent the terminal A. Let us further assume that at the point *b*, the attenuation conditions are such that the current will be reduced to one-fifth its value at the point a, so that it will have a value of five units, as represented by the heavy arrow at the point b. At the point c, adjacent the terminal B, the current will be again attenuated to one-fifth the value at point b, so that it will have a magnitude of one arbitrary unit, as represented by the heavy arrow at the point c. If, now, a current flowing in the line L_1 induces a current a thousandth as great in the line L_2, the current induced in the line L_2 from the line L_1 at the point a will have a value of .025 units. This induced current will in effect be transmitted towards both terminals A and B, this condition being indicated by the upper arrows adjacent the line L_2 at the point a. Consequently, a current having a value of .025 units will be transmitted towards the station A at the point a, due to the induction at the point a. The current of this value transmitted towards the point b is attenuated during transmission so that at the point b it has a value of .005 units and at the point c it has a value of .001 units.

The current induced in the line L_2 at the point b will have a value of one thousandth of the current flowing over the line L_1 at that point. Consequently, the induced current in the line L_2 at the point b will have a value of .005 and this current tends to be transmitted towards both stations A and B, as indicated by the arrows in the middle dotted line adjacent the line L_2 at the point b. This current is attenuated to a value of .001 in being transmitted from the point b to the point a and is attenuated to the same value, .001 during transmission from the point b to the point c. Similarly, the current transmitted over the line L_1 at the point c has been attenuated to the value of one unit and the resultant current induced in the line L_2 at this point will have a value of .001 units. The induced current tends to be transmitted towards both stations A and B. This current in being transmitted from c to a, is attenuated to the value of .00004 units, but at the point c, as already stated, will have the value of .001 units.

It will be observed that all of the currents appearing at the point c, as a result of induction at the three different points along the line, a, b and c, have the same value .001 and the total induced current appearing at the point c, as a result of induction at the points a, b and c, will be .003 in the worst case when all three currents add directly. On the other hand, the total current appearing at the point a will have a value of .02604, (in the worst case when all three currents add directly) which is almost ten times as great as the current at the point c. The magnitude of the current at the point a is due largely to the current directly induced from the line L_1 to the line L_2 at said point and the ratio may be larger than 10 times when the three currents at point c do not add directly.

Now, the induced current appearing at the point a and transmitted towards station A may be considered as cross-talk induced in a channel transmitting in the opposite direction to that of the inducing channel of the line L_1. Likewise, the induced current flowing towards the station B in the line L_2 may be considered as the current induced in a channel transmitting in the same direction as the inducing channel. If, then, we consider that a signaling current is transmitted over the line L_2 in the same direction as that which has already been considered as being transmitted over the line L_1, and this signaling current has the same value as that transmitted over the line L_1, it will arrive at the point c with a value of one unit, whereas the cross-talk current induced by the line L_1, transmitting in the same direction, will have a value of only .003 or, in other words, is only three-thousandths as great as the signaling current. On the other hand, if we consider a signaling current transmitted over the line L_2 in the opposite direction, it will be apparent that this signaling current will arrive at the point a with a value of one unit, whereas, the cross-talk at that point induced from the line L_1 will have a value of .02604 units, or, roughly, almost three-hundredths of the signaling current.

From the above, it becomes at once apparent that if we can eliminate the current induced by a given channel on one line in a channel transmitting in the opposite direction over another line, one of the greatest difficulties due to cross-talk will disappear, and we will only have to deal with the cross-talk currents of relatively small magnitude appearing in channels transmitting in the same direction.

This may be done by arranging the channels on adjacent circuits as indicated by the curves of Fig. 5. In this figure, two circuits 1 and 2 are considered, each having three channels transmitting in each direction. If in the case of each circuit the channels transmitting in one direction have assigned to them frequencies of 6,000, 9,000 and 12,000 cycles respectively and those transmitting in the opposite direction have carrier frequencies of 15,000, 18,000 and 21,000 cycles respectively, it will be apparent that all the channels transmitting in the same direction over both lines may be grouped in one frequency range, and all of the channels transmitting in the opposite direction on both lines may be grouped in another range. The carrier frequencies and the direction of transmission are indicated by the arrows in Fig. 5. The channels may be separated from each other by suitable band filters of a type well known in the art and having characteristics indicated by the curves adjacent the carrier frequencies of the two circuits. The two groups of frequencies may be separated from each other by means of a high-pass and low-pass filter, the characteristics of which are represented by the upper curves in the figure. It will be noted that the point of separation between the two groups is the same in the case of circuit 1 as in the case of circuit 2, and that all channels in both circuits below this point transmit in the same direction and all channels in both circuits above this point transmit in the opposite direction.

When these circuits are arranged as above described, the distribution of the cross-talk currents will be as indicated in Fig. 4. In this figure, the filters schematically indicated at F_1 and F_2, are the low-pass and high-pass filters, whose characteristics are shown in the curves of Fig. 5. The lines L_1 and L_2 at the terminals are divided into two branches, passing through the filters and suitable carrier apparatus schematically indicated. The carrier apparatus is of a type well known in the art. The apparatus associated with the filters F_1 at the station A serves to translate the low frequency signals from a plurality of terminal lines into signals of carrier frequency which are superposed upon and transmitted over the multiplexed lines. The carrier apparatus associated with the filters F_2 at the station A, on the other hand, serves to translate the received signals of carrier frequency into low frequency signals and to distribute the low frequency signals to the proper terminal lines. The carrier apparatus at the station B is the same as that at station A except that the apparatus associated with the filters F_2 is the transmitting carrier apparatus and the apparatus associated with the filters F_1 is the receiving apparatus. The arrows associated with the carrier apparatus indicate the direction of transmission.

With the carrier frequencies arranged as indicated by the curves of Fig. 5, it will be apparent that the cross-talk components induced in the line L_2 by the currents flowing from west to east in the line L_1 can only flow over the circuit L_2 from west to east, in other words, the cross-talk components tending to flow in the opposite direction and into the receiving channel at station A will be suppressed by the filter F_2 and only the cross-talk of small magnitude corresponding to that illustrated at the point c in Fig. 2 will be transmitted. Likewise, for signaling currents transmitted from east to west in line L_1, only the cross-talk currents of small magnitude transmitted in the same direction will be effective, the larger cross-talk currents transmitted in the opposite direction being suppressed by the filter F_1 at the station B.

In certain instances, the elimination of the near end cross-talk in the manner above described would be sufficient, as the far end cross-talk may be small enough in magnitude to be neglected. If, however, the far end cross-talk assumes such proportions as to be objectionable, the lines may be transposed in the usual manner to still further reduce the cross-talk. The number of transpositions required will, of course, be greater than in the case of an ordinary telephone circuit and the transpositions will necessarily involve more expense than in the case of the ordinary telephone circuit. The mechanical inaccuracy of the transpositions, however, will be a less serious matter where the frequencies are offset as above described, for the reason that a much lesser volume of cross-talk will remain to be taken care of. Consequently, the method of frequency separation when supplemented by transpositions will very effectively take care of the cross-talk problem and will not involve the expense of mechanically accurate transpositions, which would be necessary if the difficulty were to be overcome by the method of transposition alone.

Instead of offsetting the frequencies in the manner shown in Fig. 1, the various channels in the several circuits involved may be arranged as indicated in Fig. 6, in which the carrier frequencies employed are "staggered". In other words frequency bands transmitted in one direction will be interspersed between those transmitted in the opposite direction. With this method it is necessary, of course, that the same frequency ranges be transmitted in the same direction over all of the circuits involved in order to prevent near end cross-talk upon any of the channels.

It is, of course, a fact that the general arrangement of frequencies indicated in either the circuit 1 or the circuit 2 of Fig. 6 is old, as applied to a single circuit, and the same holds true for the grouping arrangement illustrated in Fig. 5. Applicant's invention, however, involves either staggering or grouping the frequencies of all of the circuits, and staggering or grouping them in such a manner that all of the channels on all of the lines transmitting in the same direction will lie in a frequency range or ranges different from all of the channels on all of the lines transmitting in the opposite direction.

It must not be assumed that this involves merely the obvious application to a plurality of circuits on the same pole line of the well known principle of staggering or grouping the carrier frequencies which had previously been employed on single circuits. For example, if two circuits were involved, instead of being arranged as in Fig. 6, the direction of transmission of each of the channels in one of the circuits might have been reversed. This would still comply with the principle of staggering but would not satisfy the requirements of applicant's invention and, in fact, would give the greatest amount of cross-talk. Likewise, in Fig. 5, the direction of transmission of each of the channels on one of the circuits might be reversed without departing from the principle of grouping the frequencies. This also would result in the most severe cross-talk conditions.

It might also happen that a different set of frequencies would be assigned to the carrier channels on one circuit from the set of frequencies assigned to the carrier channels on the other circuit. This also would result in a departure from the conditions required in the practice of applicant's invention.

These factors are illustrated in Fig. 7. Referring to this figure, the frequency distribution of two circuits B and C is shown. The arrangement of circuit B is typical of a well known distribution of frequencies involving the grouping principle as it was known prior to applicant's invention. Three two-way channels are involved, each transmitting in one direction on carrier frequencies of 6,000, 9,000 and 12,000 cycles and in the opposite direction on carrier frequencies of 15,000, 18,000 and 21,000 cycles. Circuit B likewise is typical of another system of distribution of frequencies in accordance with the grouping arrangement as it was known prior to applicant's invention. This is a system involving four two-way channels. These channels transmit in one direction on frequencies of 6,666, 10,000, 13,333 and 16,666 cycles and transmit in the opposite direction upon frequencies of 23,333 cycles, 26,666 cycles, 30,000 cycles and 33,333 cycles. It is at once apparent that both circuits B and C involve the grouping principle. Yet it is equally evident that the channels of circuit B transmitting on 15,000 and 18,000 cycles and the channels of circuit C transmitting on 13,333 and 16,666 cycles will produce near end cross-talk, each upon the other. Likewise, it is obvious that if the direction of transmission in each of the channels of circuit B, for example, be reversed, near end cross-talk will be produced between the 9,000, 12,000 and 21,000 cycle channels of circuit B and the channels of circuit C transmitting on 6,666 cycles, 10,000 cycles and 23,333 cycles.

In order to comply with the principles of applicant's invention, the frequency distribution of circuit B should be changed to that shown in connection with circuit B′. For example, the carrier frequencies for transmitting in one direction might be 12,000, 15,000 and 18,000 cycles and in the other direction the carrier frequencies might be 21,000, 24,000 and 27,000 cycles. With this change it will be apparent that the point of segregation between the two groups of channels on both circuits is substantially the same so that no near end cross-talk will result if all of the channels on all of the lines below the point of segregation transmit in the same direction and all the channels on all of the lines above this point transmit in the opposite direction.

It would also be possible to produce this result by shifting all of the frequencies of the circuit C down in the frequency spectrum about 6,000 cycles so that the point of segregation in the case of circuit C would coincide with that of circuit B. Bearing in mind that the frequency distributions of circuits B and C are typical of two types of circuits which have actually been used in practice, it will be apparent that applicant's invention involves a distinct departure from a mere application of the principle of frequency separation to a plurality of circuits.

It will be obvious that the general principle herein disclosed may be embodied in other and different forms without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in filtering out of any channel transmitting in a given direction over any line near end cross-talk induced from all channels transmitting in the opposite direction over an adjacent line.

2. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in assigning to all of the channels of each line transmitting in one direction frequencies different from the frequencies used in transmitting in the opposite direction over any of the lines, thereby substantially eliminating near end cross-talk.

3. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so arranging the frequency bands used for transmission in one direction on all of the lines that they will be for the most part out of coincidence with any of the frequency bands transmitting in the opposite direction on any of the lines, thereby substantially eliminating near end cross-talk.

4. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines par-

alleling each other, the method which consists in so assigning frequencies to the various channels that all of the channels transmitting in one direction on all of the lines will lie above a predetermined frequency and all of the channels transmitting in the opposite direction on all of the lines will lie below said frequency, thereby substantially eliminating near end cross-talk.

5. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that the transmission bands used for transmitting in one direction on all of the lines will coincide, and the transmission bands used for transmitting in the opposite direction on all of the lines will coincide, thereby substantially eliminating near end cross-talk.

6. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that the transmission bands used for transmitting in one direction in each circuit will not overlap the transmission bands used for transmitting in the opposite direction on the same circuit, the transmission bands of the various lines being so related to each other that all of the bands transmitting in one direction over all of the lines will coincide and all of the bands transmitting in the opposite direction over all of the lines will coincide, thereby substantially eliminating near end cross-talk.

7. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that any band transmitting in a given direction over any one of the lines will lie in a different range from the corresponding band transmitting in the opposite direction over the same line, and will also lie in a different range from all of the bands transmitting in the opposite direction on adjacent lines, thereby substantially eliminating near end cross-talk.

8. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that all of the bands transmitting in the same direction on all of the lines will lie in ranges of the frequency spectrum differing from the ranges employed by any of the bands transmitting in the opposite direction over any of the lines, thereby substantially eliminating near end cross-talk.

9. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that all of the bands transmitting in the same direction on all of the lines will lie in ranges of the frequency spectrum differing from the ranges employed by any of the bands transmitting in the opposite direction over any of the lines, and filtering from each of the channels cross-talk induced by any channel transmitting in the opposite direction on any line, thereby substantially eliminating near end cross-talk.

10. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in filtering out of any channel transmitting in a given direction over any line near end cross-talk induced from all channels transmitting in the opposite direction over an adjacent line, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

11. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in assigning to all of the channels of each line transmitting in one direction frequencies different from the frequencies used in transmitting in the opposite direction over any of the lines, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

12. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so arranging the frequency bands used for transmission in one direction on all of the lines that they will be for the most part out of coincidence with any of the frequency bands transmitting in the opposite direction on any of the lines, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

13. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so assigning frequencies to the various channels that all of the channels transmitting in one direction on all of the lines will lie above a predetermined frequency and all of the channels transmitting in the opposite direction on all of the lines

will lie below said frequency, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

14. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that the transmisson bands used for transmitting in one direction on all of the lines will coincide and the transmission bands used for transmitting in the opposite direction on all of the lines will coincide, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

15. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that the transmisson bands used for transmitting in one direction on each circuit will not overlap the transmission bands used for transmitting in the opposite direction on the same circuit, the transmission bands of the various lines being so related to each other that all of the bands transmitting in one direction over all of the lines will coincide and all of the bands transmitting in the opposite direction over all of the lines will coincide, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

16. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that any band transmitting in a given direction over any one of the lines will lie in a different range from the corresponding band transmitting in the opposite direction over the same line, and will also lie in a different range from all of the bands transmitting in the opposite direction on adjacent lines, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

17. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that all of the bands transmitting in the same direction on all of the lines will lie in ranges of the frequency spectrum differing from the ranges employed by any of the bands transmitting in the opposite direction over any of the lines, thereby substantially eliminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

18. In a transmission system in which a plurality of channels transmit in each direction over each of a plurality of lines paralleling each other, the method which consists in so choosing the carrier frequencies of the various channels that all of the bands transmitting in the same direction on all of the lines will lie in ranges of the frequency spectrum differing from the ranges employed by any of the bands transmitting in the opposite direction over any of the lines, filtering from each of the channels cross-talk induced by any channel transmitting in the opposite direction on any line, thereby substantially elminating near end cross-talk, and in transposing the conductors of adjacent lines to reduce far end cross-talk.

In testimony whereof, I have signed my name to this specification this 7th day of December 1922.

LLOYD ESPENSCHIED.