

June 27, 1933.

H. NYQUIST

1,915,442

CABLE CONDUCTOR SYSTEM

Filed Dec. 17, 1931

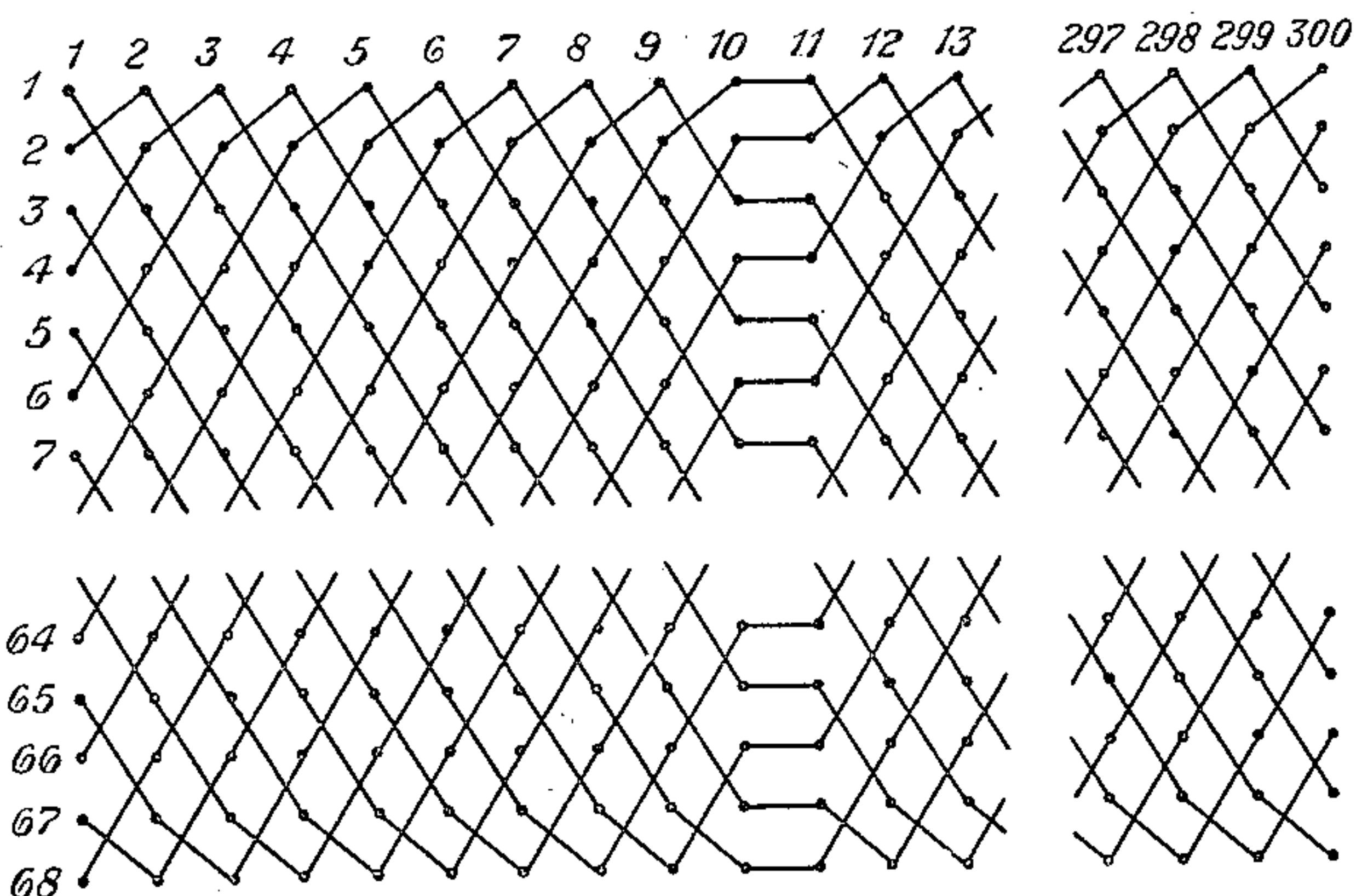


Fig. 1

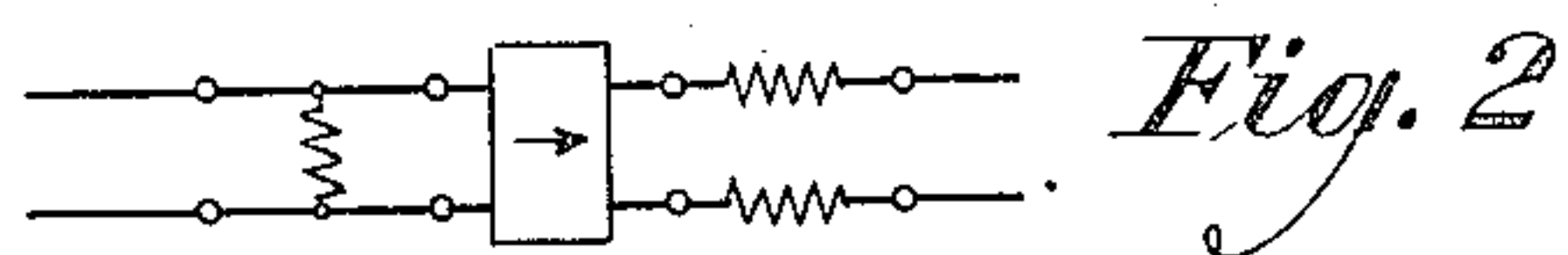


Fig. 2

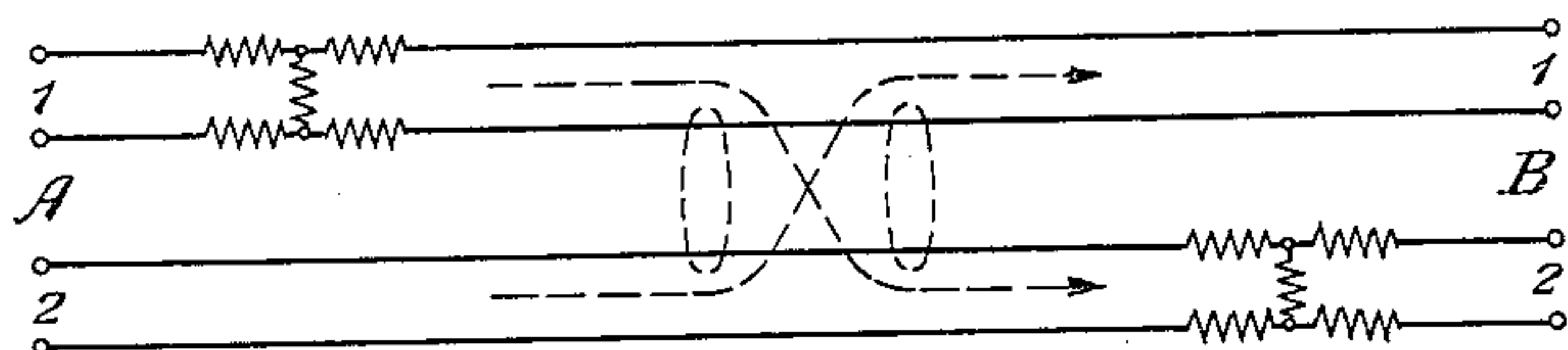


Fig. 3

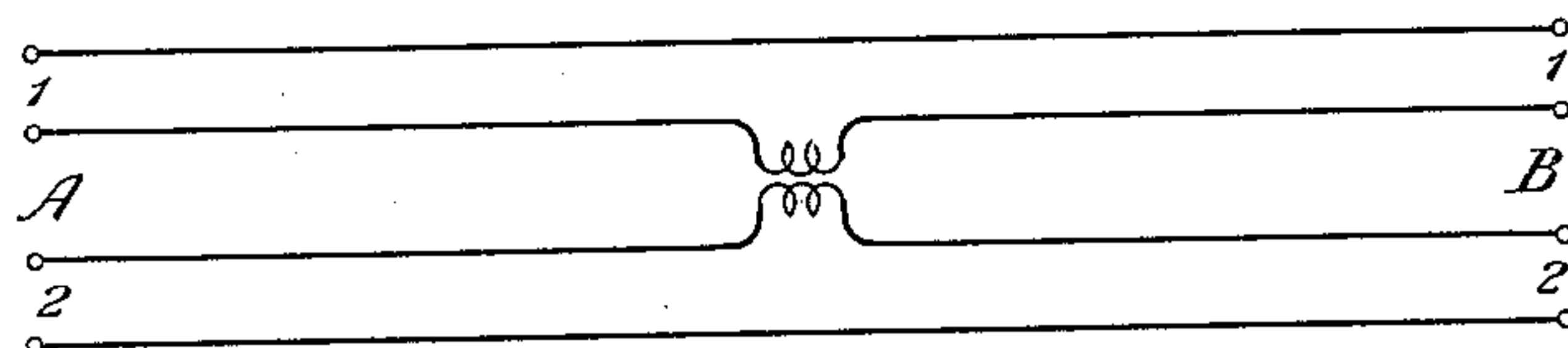


Fig. 4

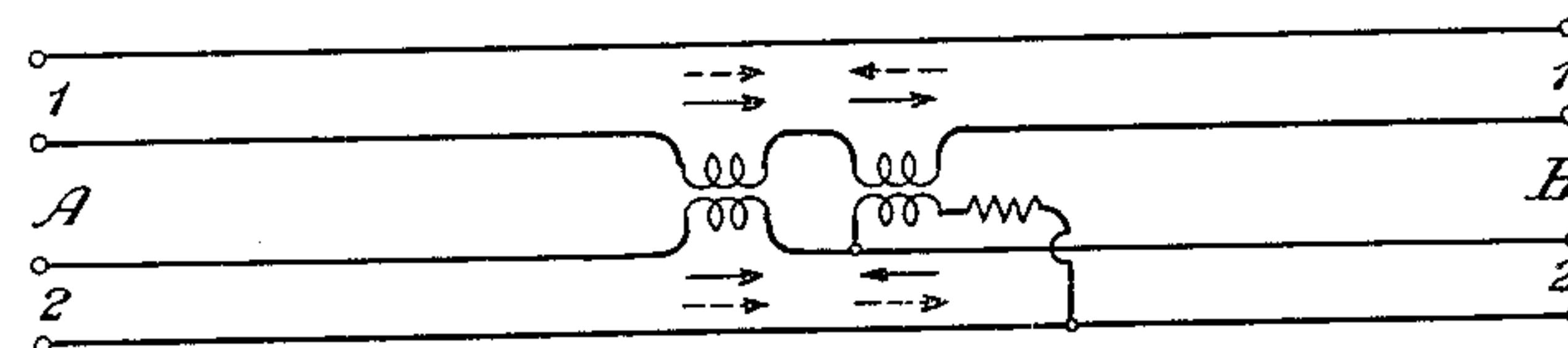


Fig. 5

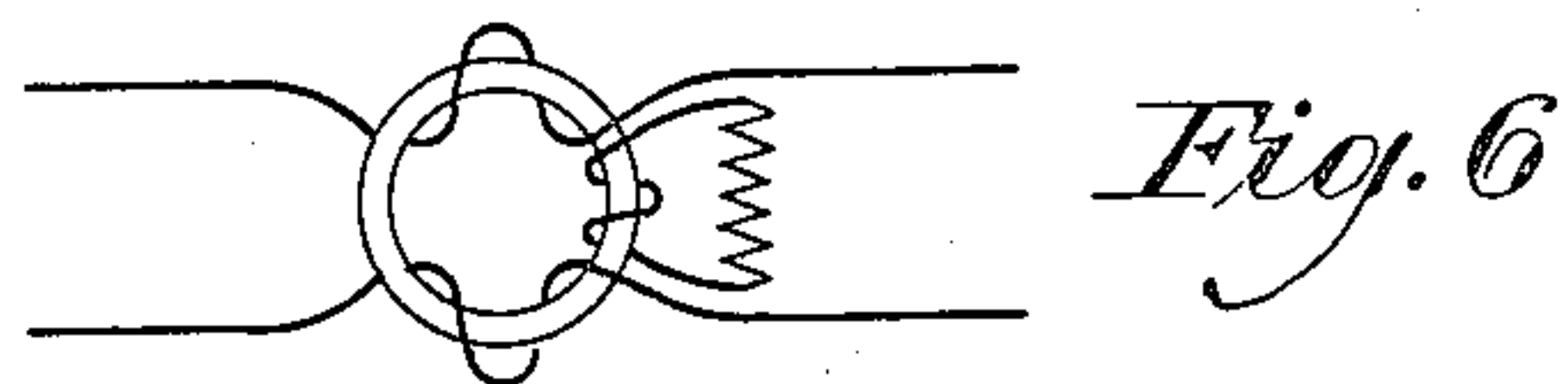


Fig. 6

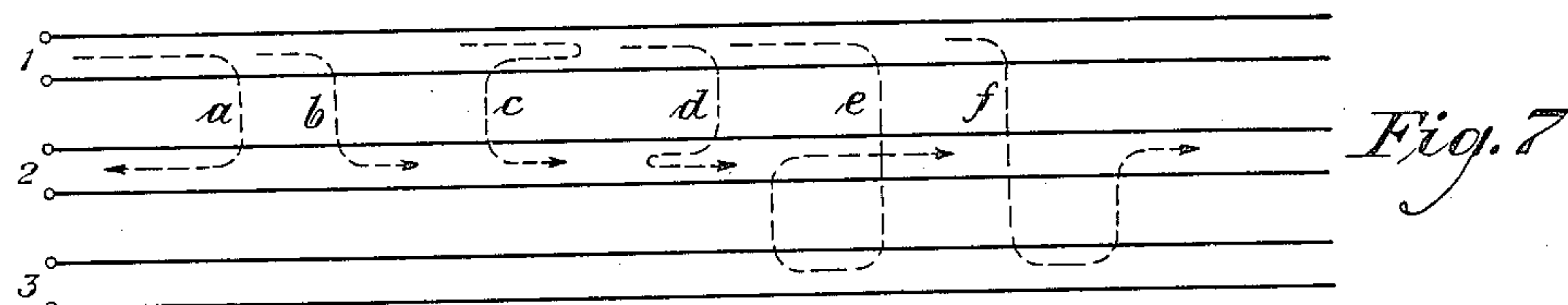


Fig. 7

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CABLE CONDUCTOR SYSTEM

Application filed December 17, 1931. Serial No. 581,741.

It is among the objects of my invention to provide a new and improved system for connecting successive lengths of conductor pairs or quads in a cable so as to improve transmission and facilitate adjustments in such pairs or quads. Another object in such a system is to remedy far-end cross-talk between such sets of conductors. Another object of my invention is to provide for connecting successive lengths of conductor pairs or quads progressively with respect to capacity or other reactance property so as to equalize all such conductor sets and facilitate the reduction of far-end cross-talk. Still another object of my invention has relation to further equalization or compensation for far-end cross-talk by introducing lumped impedance devices in connection with such conductor sets. All these objects, and other objects and advantages of my invention will become apparent in connection with the following disclosure of a limited number of specific examples of practice according to the invention, which I have chosen for disclosure in the following specification. It will be understood that this disclosure relates principally to these particular examples of the invention, and that the scope of the invention will be indicated in the appended claims.

Referring to the drawing, Figure 1 is a diagram showing a system of connections for successive lengths of conductor pairs in a cable according to my invention; Fig. 2 is a diagram showing supplementary means for equalizing the impedance of conductor pairs at repeaters; Fig. 3 is a diagram illustrating the nature of asymmetrical far-end cross-talk; Fig. 4 is a diagram showing a device for correcting symmetrical far-end cross-talk; Fig. 5 is a diagram showing a device for correcting asymmetrical far-end cross-talk; Fig. 6 is a diagram showing a device to reduce reaction cross-talk; and Fig. 7 is a diagram to show the nature of different kinds of cross-talk.

In laying a multi-conductor cable, successive reel lengths are placed end to end and the pairs in one reel length are spliced to corresponding pairs in the next reel length to provide continuous conductor pairs

through a number of such reel lengths. For example, a cable may have 68 pairs and between two successive repeater stations, it may consist of 300 reel lengths spliced together at 299 junctions.

A pair in one reel length is likely to vary somewhat in capacity per unit length as compared with a pair in another reel length. If such pairs are spliced together, it means that successive line sections are of different impedance and there are, accordingly, reflections of energy at the various junctions. The most obvious method of connecting successive sections is to connect them together at random. However, this results in large reflections in some cases. The system here to be described may be explained by means of the specific example, namely, 68 pairs in 300 reel lengths, as mentioned above.

Each of the 68 pairs in one reel length is tested for capacity and these pairs in this reel length are designated in the order of their capacities. In Fig. 1, the cable is represented diagrammatically as extending lengthwise horizontally across the figure. Each dot represents a pair in a reel length; thus a column of dots represents a complete reel length. These pairs in a single reel length, represented by a column of dots, are to be thought of as arranged in the order of descending capacity from top to bottom. Thus in reel length numbered 5, the pair of highest capacity is represented by the dot at the top of the column, the pair next highest in capacity by the next dot in the column, and so on, the pair of lowest capacity being represented by the lowermost dot in the column.

Beginning at the left-hand end, the pairs in the first reel length are connected to those in the second reel length, as indicated by the links joining the dots at the left of Fig. 1. Thus pair 1 in the first reel length is connected to pair 3 in the second reel length, which in turn is connected to pair 5 in the third reel length, and so on. These connections beginning at the left and extending as far as reel length 10 are fully indicated in the left part of Fig. 1 and will require no further verbal description.

If the connections were continued through

the whole length of the cable, according to the plan that has just been described, then pair 1 in the first reel length would eventually be connected with pair 68 of lowest capacity in the thirty-fifth reel length, and in thirty-three more reel lengths, that is, in reel length No. 68, the continuous conductor pair from the beginning would have been shifted from a pair of highest capacity, namely, pair 1 in reel length 1 to a pair of lowest capacity, namely, pair 68 in reel length 35, and then back to a pair of next to the lowest capacity, namely, pair 2 in reel length 68. Such a cycle will be called a wave. Continuing in this way, four times 68, or 272 reel lengths, would make four complete waves or cycles, leaving twenty-eight more reel lengths to be connected. It is desirable to come out with a pair at the distant end of the cable at the same level at which we went in and, therefore, twenty-seven "straight" connections are distributed uniformly along the length of the cable, as shown for one such connection in Fig. 1 between the reel lengths numbered 10 and 11. We have just mentioned that four complete waves or cycles will carry us from reel length 1 to reel length 272. But interspersing these twenty-seven straight connections will carry us to reel length 299, and continuing according to the wave plan into reel length 300, will bring us to positions at the right corresponding exactly with those for the same conductor pairs at the left; that is, the pair that begins at the left at highest capacity 1 in reel length 1 will come out at the right in the pair of highest capacity 1 in reel length 300, and similarly for other pairs.

As already mentioned, there are twenty-seven straight connections to be distributed in 300 reel lengths.

There will be 28 intervals between the ends and the straight connections and hence the number of reel lengths between consecutive straight connections will be an integer near $300/28$ which is 10 and $20/28$. Multiplying this by 1, 2, 3, etc. for successive intervals the numbers 10 and $20/28$, 21 and $12/28$, 32 and $4/28$, etc. are obtained. The straight connections will accordingly be located between the 10th and 11th reel lengths, between the 21st and 22nd, between the 32nd and 33rd, and so on.

Of course the impedance of a pair is dependent on inductances as well as on capacity. But the capacity and inductance are correlated rather definitely. If we think of the two conductors as being moved further apart to decrease the capacity between them, this will increase the self-inductance of that circuit at the same time and in about the same ratio. This will be the justification for fixing our attention on the capacity in the following discussion and saying little directly about the inductance.

It will be apparent that the circuit of each

pair in the system built up according to the foregoing plan will be relatively free from reflections, for the capacity of the pair in one reel length will be very little different from the capacity of the pair in the consecutive reel length so there will be very little impedance difference at junction points to occasion reflections. Moreover, the sixty-eight circuits will be substantially equal in total attenuation because each circuit-pair goes four times through the cycle from highest to lowest impedance and thus the circuit pairs are substantially alike. However, there will inevitably be some difference between the pairs in terminal impedance, that is, in the impedance presented by a pair at the terminal office. In order to get the benefit of the kind of splicing that has been described, the office impedance connected to the different pairs should be made adjustable and should fit the impedance of the pair in the nearest reel length as nearly as practicable. A convenient way of doing this is to build the repeater so that its output impedance fits substantially the lowest impedance that will be encountered and its input impedance fits substantially the highest impedance that will be encountered. Then the repeaters can be built out as indicated in Fig. 2 by series resistances on the output side and shunt resistances on the input side, these resistances being adjusted to fit the line. In this way, a line of low impedance at its ends will have very little building out where it connects to the output of the repeater but will have relatively much building out where it connects at the other end with the input of another repeater, and vice versa for circuits which are of high impedance at the ends. As a result, the total building out connected to any circuit will tend to be approximately constant and the total attenuation of the line, including the building out resistances at both ends, will tend to be constant, as comparing one pair with another among the sixty-eight pairs.

In order to get the fullest advantage of this type of splicing, it should be combined with allocation of reels. This can be done by measuring the average capacity of the pairs in available reels and then arranging the reels so that no two reels having widely different average capacity per unit length are adjacent to each other. The preferred arrangement is to arrange the reels in ascending or descending order of average capacity per unit length. However, such a complete allocation would be rather inconvenient, and would be unnecessary unless extreme avoidance of irregularity were desired.

It will readily be seen that the foregoing system for 300 reel lengths and sixty-eight pairs might be modified by introducing a greater number of straight splices and having a less number of complete waves or cycles

from end to end of the system. However, there should be an integral number of these waves or cycles in any case and it will be better not to have the number too small, as for example, merely one complete wave or cycle, for in the case of only one complete wave or cycle the cross-talk between two pairs may be asymmetrical. This is illustrated in Fig. 3 where two pairs 1 and 2 are represented extending between the points A and B. The networks in these pairs represent excessive attenuation at the points where they are placed. It will readily be seen that far-end cross-talk from A—1 to B—2 suffers attenuation through both the networks, whereas far-end cross-talk from A—2 to B—1 is not attenuated in either network. The result will be greater far-end cross-talk from A—2 to B—1 than from A—1 to B—2. But in the correction of cross-talk, it is far more convenient to have it symmetrical. Such correction may be effected, for example, as shown in Fig. 4 by an inductive linkage between a properly chosen conductor of one pair and a properly chosen conductor of the other pair. Such correction is obviously symmetrical and, therefore, if the far-end cross-talk is not symmetrical it cannot be accurately corrected in this way. Thus an advantage of the multiple wave system, indicated in Fig. 1, is that it tends to reduce asymmetric far-end cross-talk and makes correction practicable by such means as shown in Fig. 4.

If the number of reel lengths is small compared to the number of pairs, the shifts at each junction may be made greater than in Fig. 1, so as to get enough complete waves from end to end. For example, instead of connecting from 1 to 3 at the upper left corner of Fig. 1, we might connect from 1 to 5 and so on. Also, should it be desired to reduce the number of waves from end to end, more straight connections may be introduced, either one at a place, or two or more consecutively at a place, these places being distributed uniformly.

It is practicable to introduce an asymmetric corrector for asymmetric far-end cross-talk if the need becomes inevitable. In Fig. 5 we see the same series transformer at the left as in Fig. 4 and, in addition, another transformer with one winding in series in one conductor of pair 1 and the other winding bridged across the conductors of pair 2 with a resistance in series. If the two transformers are poled so as to be series aiding in transmission from A—1 to B—2, and as indicated by the solid line arrows, then they will be opposing in transmission from A—2 to B—1, as indicated by the dotted line arrows. Accordingly, the far-end cross-talk components due to the corrector shown in Fig. 5 will be greater from A—1 to B—2 than from A—2 to B—1 and will therefore cor-

rect normal far-end cross-talk which is asymmetric in the opposite sense.

There is another kind of lumped corrector shown in Fig. 6 which is of advantage to remedy reaction cross-talk. The nature of reaction cross-talk will be pointed out in connection with Fig. 7. Here we consider transmission from left to right. From the line 1 to the line 2 the arrow *a* represents ordinary near-end cross-talk and the arrow *b* represents ordinary far-end cross-talk. There is another variety of far-end cross-talk which arises from near-end cross-talk with one reflection. This is shown by the arrows *c* and *d*, according to whether the reflection occurs in the first pair or the second pair. Such reflection far-end cross-talk appears as ordinary far-end cross-talk except that it will be somewhat displaced in phase. Reaction cross-talk is as represented by the arrows *e* and *f*. Here a third pair 3 is involved, and in the first stage as shown by arrow *e*, there is ordinary near-end cross-talk from pair 1 to pair 3. Then again there is another stage of near-end cross-talk from pair 3 to pair 2, giving a resultant far-end cross-talk from pair 1 to pair 2. Similarly, as shown by arrow *f*, reaction far-end cross-talk may arise as the resultant of two stages of far-end cross-talk.

The ordinary far-end cross-talk as represented in arrow *b* can be eliminated to a large extent by means of balance, as suggested in a simple manner in Fig. 4. The reflection cross-talk such as indicated by the arrows *c* and *d* in Fig. 7 can be minimized by avoiding impedance irregularities in the line which would give rise to reflections. This is accomplished in the foregoing described system of Fig. 1. It is to be noticed that reaction cross-talk such as represented by arrows *e* and *f* involves a third pair in addition to the two pairs between which the cross-talk occurs. This intermediate pair, instead of being physically distinct as in Fig. 7, may be a useless phantom on pairs 1 and 2, or a useless phantom between one of these and a third pair such as 1 and 3; or the intermediate circuit may be a circuit established by a degree of grounding of one or more pairs. When the intermediate circuit represented by 3 in Fig. 7 is a physical pair, the reaction cross-talk, represented by *e*, will be relatively small for the reason that near-end cross-talk is known by experience to be small enough so that two such stages of near-end cross-talk in tandem would not be great. Therefore it is inferred that the chief intermediaries in the case of reaction cross-talk, represented symbolically by 3 in Fig. 7, will be the various phantoms and grounded circuits, as mentioned above. Currents flowing in such phantoms and grounded circuits will flow alike in the two conductors thereof, whereas the normal use-

ful voice currents flow in opposite phase in the two conductors of a pair. Accordingly, a transformer system such as represented in Fig. 6, is interposed in each pair. For the normal transverse currents of the pairs it will be seen that the two windings in the respective conductors of the pair buck each other, so that they have practically no reactive effect. But for currents flowing in the same direction in the two conductors, these windings are series aiding on the magnetic circuit and, therefore, an inductive reactance is set up. The third winding on the core has a resistance in series therewith so that the flux set up in the core by the phantom currents leads to a dissipation of energy in the resistance. In this way the normal transverse voice currents are not damped by the device, but the abnormal or parasitic phantom currents have their energy dissipated in the resistances. These devices, such as shown in Fig. 6, will be inserted in all the pairs in the cable at suitable intervals which may be at every splice, or at intervals of a few reel lengths. The net effect of the application of these devices in all the pairs is to increase the attenuation in all circuits other than pairs, without impairment of the normal current flow in the pairs. Inasmuch as the intermediate or third medium in reaction cross-talk is generally some such other circuit, the devices will serve greatly to reduce the reaction cross-talk.

The two interposed windings of the device shown in Fig. 6 should be as nearly perfectly coupled as possible so that the inductance to transverse currents in the pair will be negligible. Moreover, these windings should have as low a capacity as possible. If it is not possible to make both the capacity and the leakage inductance negligible, the coil should be designed so that its characteristic impedance will be equal to that of the pair.

The foregoing disclosure has had relation principally to smooth lines. Such lines may be worked with carrier currents at high frequencies, for which the capacity effects between the conductors of a pair become considerable, and the proper joining up of successive reel lengths according to my invention becomes of considerable importance. To a degree, the principles of my invention may be utilized for loaded lines with cable pair sections extending between the loading coils. In this case the current frequencies will not be as high as for smooth carrier current circuits and the capacity reactances will not be as high, and therefore, it becomes unimportant to systematize the splicing between reel lengths. But the same system of splicing between reel lengths that is disclosed in connection with Fig. 1 for smooth lines may advantageously be employed for loading sections of loaded lines.

The principal aim of wave splicing in the case of high frequency carrier cables is to reduce reflection cross-talk. In the case of loaded circuits the aim is to have the line present a smooth impedance to the repeater office, which makes it suitable for two way operation. Here we deal with two wire circuits with transmission both ways, whereas in the case of the smooth lines heretofore considered we dealt with one-way transmission in four-wire circuits.

The loaded lines here considered will generally be phantom so that we must deal with quads, each quad comprising two side circuits. A procedure in accordance with my invention will be to complete all the intermediate splices but without the loading coils connected at either end, then measure the capacity between the two conductors of each side circuit pair in a given group in each loading section, then add the capacities of the two side circuits in each quad. Call the quad for which such added capacities give the highest result, No. 1, the next No. 2, then No. 3, and so on. Measure the circuits and number the quads in the same way in all the loading sections. For convenience let us assume a particular loading coil station and let the numbers stand as thus obtained on the east but let them be primed, that is, 1', 2', 3', etc., on the west. Assuming that the cable has fourteen quads, let them be connected at this loading coil station according to the same general plan as in Fig. 1, but without straight splices, that is, in accordance with the following table.

1-3'	2-1'
3-5'	4-2'
5-7'	6-4'
7-9'	8-6'
9-11'	10-8'
11-13'	12-10'
13-14'	14-12'

Within each quad, pole the pairs so that the pair with the highest capacity in that quad goes to the pair of the highest capacity in the quad of the associated section according to the above table.

It has been stated above that for loaded lines with their lower frequency as compared with smooth carrier current lines, there is no advantage in wave splicing for connecting the reel lengths between loading coil stations. It may properly be considered that this is because the phase shift in all the reel lengths making up one such section is comparatively small, and this is due to the fact that the frequency of current involved is much lower. However, it may be worth while to have some degree of system for connecting the reel lengths instead of doing it in a purely random fashion. The reel lengths may be spliced together in a compensatory manner so that the total capacity

per loading section is as nearly the same as practicable, for all the different circuits. Suppose, for simplicity, that a cable is made up of pairs only, that is, no quads. Suppose, further, that one loading section comprises eight reel lengths. Then a simple procedure is to connect the first reel length to the second, the third to the fourth, the fifth to the sixth, and the seventh to the eighth, so that the highest capacity pair in the first reel length is connected to the lowest capacity pair in the second, the next highest in the first is connected to the next lowest in the second, and so on. After this, the junctions of the second to the third and the sixth to the seventh may be made according to the same procedure, having regard to the capacities of the double length sections that have been established to this point. Finally, the fourth and fifth lengths may be connected in the same way, having regard to the capacities of the quadruple length sections that have been built up to this point. The advantages of this kind of connection may be reached to a degree but sufficiently, by taking part of these steps but adopting random splicing to some extent. It is also desirable to make use of allocation of reels in such a manner as to make the average capacity the same in all loading sections.

Usually the deviations in the loading coils do not cause as great irregularities as the deviations in the line capacities. When the latter have been taken care of, as disclosed heretofore, it may be that the loading coils will contribute enough irregularity to make it desirable to systematize their connections. First assume that the loading coils are substantially alike in respect to capacity, and grade them according to inductance. In this case increased uniformity can be obtained according to either of two plans. The first plan is to connect the highest inductance coil between the highest capacity pairs, the second highest inductance coil between the next highest capacity pairs, and so on. The second plan is to connect the highest inductance coil between the lowest capacity pairs, the next highest coil between the next lowest pairs, and so on. The first plan is thought preferable when the cut-off of the loading is high in comparison with the highest frequency used. When the cut-off frequency is only slightly greater than the highest frequency used, the second plan is thought preferable.

But there may be variations in the coil capacity of sufficient importance to be considered. In this case the coils are arranged as before from highest to lowest but instead of having regard only to pure inductance they are arranged in descending order of the quantity $L - R^2/C$, where L is the coil inductance, R is the characteristic impedance of the line, and C is the coil capacity. The

propriety of this formula will be recognized when it is remembered that capacity annuls a certain fraction of the inductance, this fraction being approximately R^2/C .

Hitherto it has been assumed that the cable is made up of pairs exclusively. In a more usual case, however, the cable is made up of quads, and the coils are made up in phantom units. In order to have a useful phantom circuit it is necessary to take care that the two pairs in a quad are not separated in any of the splices and, likewise, that the two pairs in a quad are connected to the loading coils which form a unit. Therefore, the procedure outlined above will not be applicable in such a case of quads, for if it were followed it would separate the pairs. The procedure to be followed in the case of quads must be a compromise as, for example, in accordance with the following plan.

In the first place it will be assumed that it is not necessary to improve the smoothness of phantom circuits. Assume that the cable contains forty quads to be spliced together. The capacity of all the pairs is measured and then the quads are grouped into say four groups of ten each, such that the first group contains the ten quads in which the difference between the two side capacities is the smallest, the next group contains the ten quads in which the difference between the side capacities is the next smallest, and finally, the fourth group contains those ten quads in which the difference between the side capacities is the greatest.

Next, each group of ten quads is arranged according to the order of the sum of the side circuit capacities so that the quad which has the highest sum for the side circuit capacities within any group of ten is assigned the number 1, etc. In splicing within any loading section, quads in corresponding groups are spliced together and within a given group a quad having the highest sum is spliced to the one having the lowest sum, etc., and within the quad a high pair is spliced to a low pair. At the loading points the practice of wave splicing is applied to the quads in accordance with the sum of the capacities of their pairs, as heretofore explained.

In respect to the manner of splicing the pairs within a given quad, the following procedure is suggested in cases where the correlation between the capacities of the two pairs of a quad is small. At each third loading point, say at points 1, 4, 7 etc., high is connected to high within the three groups of ten quads having the greatest difference between the pairs. In the group having the smallest difference between the pairs, high is connected to low at these points. At the loading points numbered 2, 5, 8, etc., high is connected to high throughout the quads in group 4 are connected to the quads in group 3 and the quads in group 2 are connected to

the quads in group 1. Finally, at points numbered 3, 6, 9, etc., high is connected to high throughout but the quads in group 3 are connected to the quads in group 2. In this manner the construction will be that of a smooth wave.

If it should be deemed desirable to improve the smoothness of the phantoms as well as of the sides, this may be done by confining the wave splicing to either the sides or the phantoms and then to obtain the smoothness in the phantoms or the sides, respectively, by means of splicing within the loading sections.

I claim:

1. The method of connecting a plurality of conductor sets in successive sections of a cable, which consists in connecting them progressively according to a reactance property of such sets from higher to slightly lower and so on and then back from lower to slightly higher and so on in an integral number of complete waves.

2. The method of connecting a plurality of conductor sets in consecutive cable sections, which consists in numbering the sets in each section in order of a reactance property, then connecting them progressively 1-3-5 etc., 2-1-3 etc., 3-5-7 etc., 4-2-1 etc., and so on through all the numbered sets in the first, second and third sections, and so on through all the sections.

3. The method of claim 2, with the qualification that straight connections are interspersed uniformly, the number of straight connections being such as to make an integral number of complete waves of progressive connections.

4. A multi-conductor cable in sections end to end, a plurality of sets of conductors in each section being graded in respect to a reactance property and the sets of conductors of these sections being connected progressively at the section junctions according to the grading.

5. A multi-conductor cable in sections end to end, a plurality of sets of conductors in each section being graded in respect to a reactance property and the sets of conductors of these sections being connected progressively at the section junctions according to the grading, the progression being carried over at least one complete wave along the length of the cable.

6. A multi-conductor cable in sections end to end, a plurality of sets of conductors in each section being graded in respect to a reactance property and the sets of conductors of these sections being connected progressively at the section junctions according to the grading, the progression being carried over an integral number of complete waves along the length of the cable.

7. A cable comprising a plurality of sections end to end with a plurality of conductor sets in each section, the sets in each section

being graded in respect to a reactance property and the sets being connected consecutively from section to section in progressive order based on such grading, the progression extending to an extreme of the graded property, then reversing, and so on through at least one complete cycle.

8. A cable as defined in claim 7 with alternative straight connections at enough of the junctions to establish an integral number of complete cycles from end to end.

9. In a multi-conductor cable, sections connected consecutively, a pair of a certain capacity in one section being connected to a pair of slightly different capacity in the next section and so on progressively from section to section until an extreme of capacity has been reached and then in opposite progression until the opposite extreme has been reached, the connections being carried thus through an integral number of complete waves or cycles from one end of the cable to the other.

10. A cable according to claim 9, with straight connections interspersed uniformly so that the progressive connection will come out in an integral number of complete waves.

11. A multi-conductor cable in sections end to end, sets of conductors in each section being graded in respect to a reactance property, and the sets of conductors of these sections being connected at the section junctions progressively according to the grading to sets of conductors of small reactance difference, so as to afford only slight impedance irregularities at the junctions and so as to give substantially the same attenuation in the connected sets of conductors.

12. Two cable lengths, each according to claim 11, and between them a repeater built to fit a low impedance on its output side, and a high impedance on its input side, and an adjusted series impedance interposed on its output side, and an adjusted shunt resistance across its input side.

13. A cable according to claim 11, and correctors for residual asymmetric far-end cross-talk interposed between the conductor sets thereof.

14. A cable according to claim 11, and apparatus units interposed in the conductor sets, these units offering substantially no impedance to transverse currents on the sets but being energy dissipators for longitudinal currents on the sets.

15. Means for equalizing asymmetric far-end cross-talk between two conductor pairs, consisting of two transformers one having its two coils respectively in series in conductors of the respective pairs and the other transformer having one coil in series in one conductor of one pair and the other coil across the other pair, and a resistance in series with the last mentioned coil.

16. Means for equalizing asymmetric far-end cross-talk between two conductor pairs,

comprising a reactance connection and an energy dissipator, said energy dissipator functioning to dissipate energy for far-end cross-talk one way but not for far-end cross-talk asymmetric thereto.

17. Means for equalizing asymmetric far-end cross-talk between two conductor pairs consisting of two transformers, their coils being connected with conductors of the pairs and poled to be aiding for far-end cross-talk one way and opposing for asymmetric far-end cross-talk the same way.

18. A transformer system to be interposed in a multi-conductor cable to remedy asymmetric far-end cross-talk, having at least three coils and a resistance in series with one coil.

19. Means to remedy reaction far-end cross-talk between conductor pairs consisting of a transformer in each pair with one winding in one side of the pair, another winding in the other side and a third winding in circuit with a resistance, the windings in the sides bucking each other for transverse currents in the pair.

20. Means to remedy reaction far-end cross-talk between conductor pairs consisting of a transformer in each pair wound to be non-reactive to transverse currents and energy dissipative to longitudinal currents.

In testimony whereof, I have signed my name to this specification this 15th day of December, 1931.

HARRY NYQUIST.