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2,080,217

APPARATUS AND METHOD FOR REMEDYING CROSSTALK

Filed Nov. 9, 1935

2 Sheets-Sheet 1

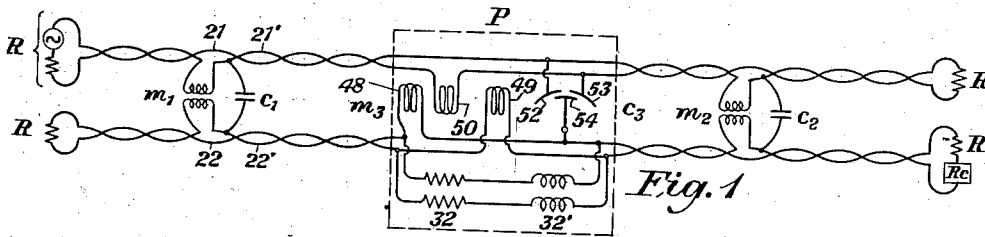


Fig. 1

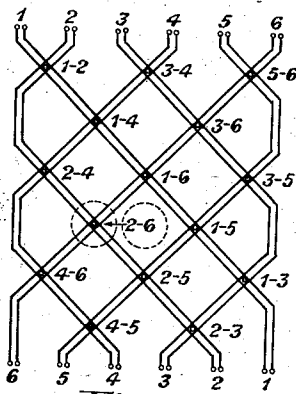


Fig. 2

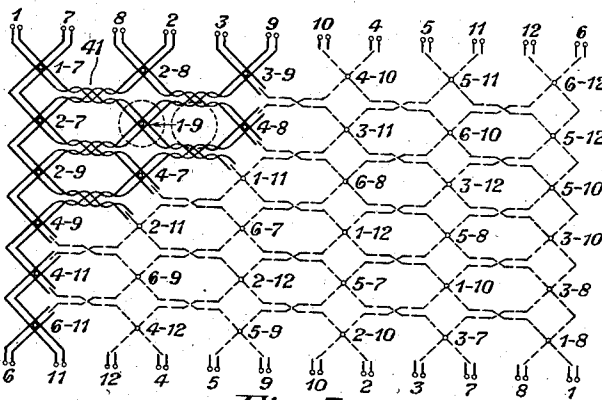


Fig. 3

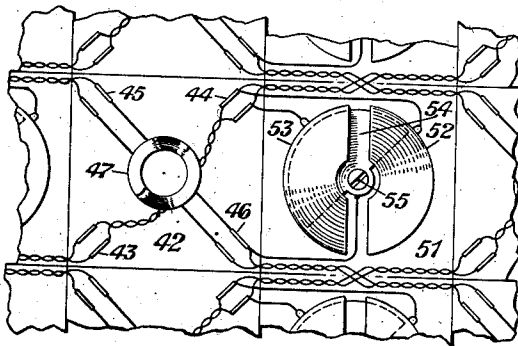


Fig. 4

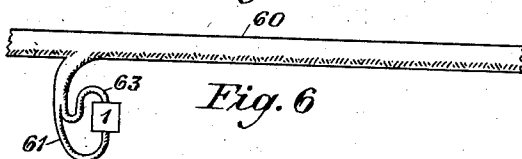


Fig. 6

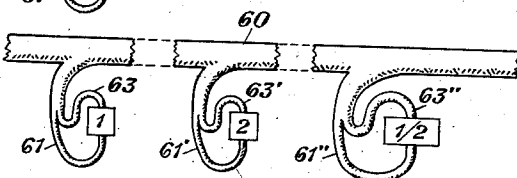


Fig. 7

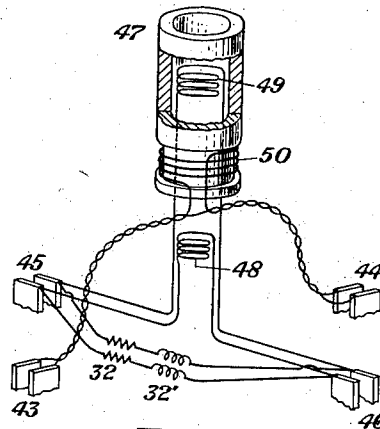


Fig. 5

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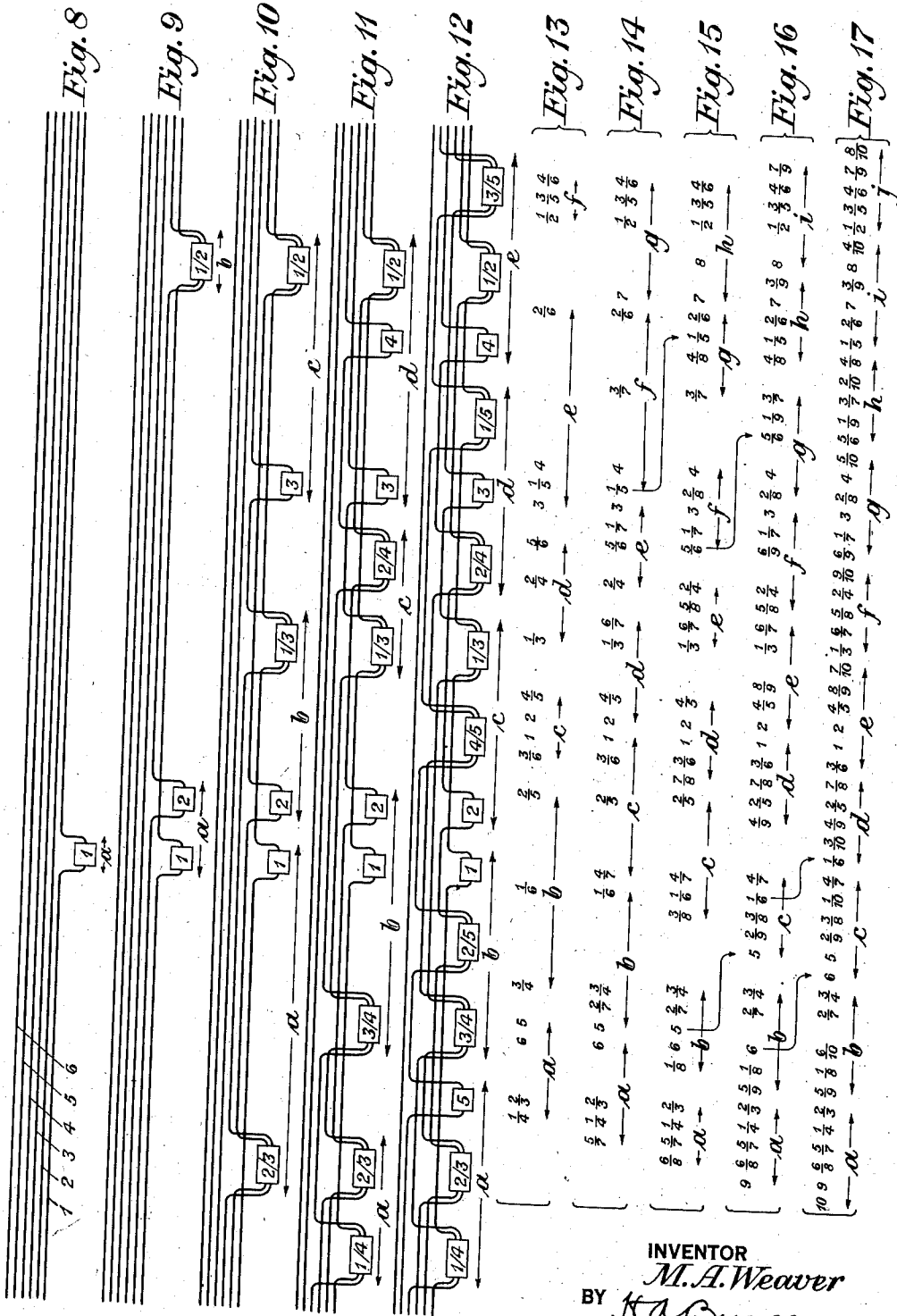
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2 Sheets-Sheet 2



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APPARATUS AND METHOD FOR REMEDYING
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Application November 9, 1935, Serial No. 48,947

8 Claims. (Cl. 179-78)

One of the principal objects of my invention is to provide a new and improved system for eliminating the objectionable effects of crosstalk in signaling circuits. Another object is to make correction or compensation for crosstalk in a system of transmission lines extending side by side. Another object is to provide a convenient system or arrangement of small adjustable reactance units for compensating crosstalk between any one and any other of a considerable number of pairs of neighboring signaling circuits. Another object is to provide such a system with adaptation for growth by increasing the number of circuits between which compensation must be made. All these objects and other objects and advantages of my invention, will become apparent on consideration of a specific example of practice in accordance with the invention which I will now disclose in the following specification. It will be understood that this disclosure has relation, primarily, to these particular examples of the invention, and that the scope of the invention will be indicated in the appended claims.

Referring to the drawings, Figure 1 is a diagram of two telephone lines between which there may be crosstalk, with adjustable means for its compensation; Fig. 2 is a diagram indicating a panel arrangement for bringing each of a number of conductor pairs in relation to each of the others for making adjustments between them; Fig. 3 is a diagram indicating a panel arrangement for bringing each of a complement of conductor pairs in relation to each of another complement for making adjustments between them; Fig. 4 is a semi-diagrammatic elevation of a fragment of the panel of Fig. 3; Fig. 5 is a diagrammatic elevation of an adjustable mutual inductance unit for connection between two pairs; Fig. 6 is a diagram indicating the relation of a cable and an adjusting panel for a single complement of pairs taken from the cable; Fig. 7 is a similar diagram for two complements of pairs taken from the cable; Figs. 8 and 9 correspond, respectively, to Figs. 6 and 7 but are more diagrammatic; Figs. 10, 11 and 12 go on from Fig. 9 in succession showing the introduction of further panels as more complements of pairs are brought into relation for balancing; Figs. 13, 14, 15, 16 and 17 are yet more diagrammatic representations than those which precede; these indicate a suitable arrangement for the panels for further successive additions of complements until ten complements have been brought into the system in Fig. 17.

There are many existent cables which are loaded and carry voice frequencies. By deloading

them and putting repeater stations at more frequent intervals, and operating them with carrier currents, their capacity may be increased. Increase of traffic and other conditions may make such a change desirable for only part of the conductor pairs in the cable at any one time. When pairs of the cable are changed over from voice frequency operation to carrier current operation, it may be necessary to balance for crosstalk in a way that was not necessary before. Hence, as successive complements of pairs are changed over, corresponding successive installations of the herein disclosed panels for balancing will be made. It is a feature of my invention that an advantageous plan for these successive installations is provided.

Referring to Fig. 1, this is a diagram showing the two twisted pairs 21-21' and 22-22' of a cable extending between two consecutive repeater stations. At these stations each pair is terminated in apparatus having the characteristic impedance R which is the characteristic impedance of either line. The modulated carrier current applied at the left end to the pair 21-21' comprises components of various frequencies, and at various places along the line there may be some unbalanced or residual inductance and capacity effects from one side or the other of the pair 21-21' into one side or the other of the pair 22-22'. Thus there may be a certain residual or unbalanced mutual inductance between the conductor 21' and the conductor 22', as indicated by m_1 , and/or there may be a capacity effect between these conductors, as indicated by c_1 . At other places along the length of these lines there may be other inductance and capacity effects, as at m_2 and c_2 .

At any convenient place along the length of the repeater section shown in Fig. 1 a panel P is installed and arranged so that adjustable mutual inductances such as m_3 and/or adjustable capacities such as c_3 , may be connected across from a conductor of one pair to a conductor of another pair so as approximately to neutralize the residual crosstalk due to such connections, as at m_1c_1 and m_2c_2 .

The panel P may be located anywhere along the length of the repeater section. An advantage in having it near one end will be the greater convenience in having it assembled at a repeater station so that it can be cared for and attended along with that station. On the other hand, the inevitable slight irregularity of impedance termination at the ends of the section makes it somewhat advantageous on this ac-

count to have the panel P about halfway between the repeater stations. In Fig. 1 it is shown located at the halfway place. The mutual inductance m_3 between the two pairs may be adjusted differentially by displacing the intermediate coil 50 in one side of one pair toward one or the other of the coils 48 and 49 in the respective sides of the other pair. The capacity correction between the two pairs may be reached by differential adjustment of the movable condenser plate 54 which is connected to one side of one pair, in relation to the two fixed plates 52 and 53, which are connected to the respective sides of the other pair. Each fixed series coil 48 or 49 is shunted by a resistance 32 and inductance 32' in series to each other in the shunt. The purpose of these elements is to make the mutual inductance characteristic of the balancing coils m_3 simulate the mutual inductance characteristic, such as m_1 , existing between any two cable pairs. Theoretical considerations which have been checked by measurements on cables show that m_1 , due to a proximity effect, is complex in character, that is, m_1 equals $m_a + jm_b$. By suitable design of the resistance 32 and inductance 32', the mutual inductance m_3 can be made to assume the proper $m_a + jm_b$ relationship.

Instead of two pairs to be balanced or compensated against each other as in Fig. 1, suppose there are six such pairs. They may be led across the face of the panel in courses such as represented in Fig. 2. It will be seen that each of the six pairs intersects each of the other five pairs once and only once in Fig. 2. Adjacent to each intersection the adjustable inductance and capacity units may be set up at the places indicated by the respective dotted circles for the intersection 2—6, and as will be shown more in detail in connection with Figs. 4 and 5.

If a large number of pairs are to be balanced each against each of the others, it may be impracticable to do this on a single panel like that of Fig. 2. For this and other reasons which will appear presently, the pairs must be handled in sets or complements and the task arises not only to balance each pair of a set against each other pair of that same set, but also to balance each pair of one set against each pair of a different set. For this purpose a panel such as shown in Fig. 3 will be employed. One set or complement of pairs consists of those pairs numbered 1, 2, 3, 4, 5, 6 and the other set or complement consists of those pairs numbered 7, 8, 9, 10, 11, 12. It will be seen that each pair of one set intersects each pair of the other set; these intersections are indicated by expressions such, for example, as 3—11, designating the intersection of pair 3 of the first complement with pair 11 of the second complement. The dotted circles adjacent to the intersection 1—9 indicate the location of the respective inductance and capacity units. Between two consecutive intersection places along a pair, the conductors of that pair are insulated and twisted together and physically crossed over another pair as indicated, for example, at 41. As convenient short names, I refer to the panel of Fig. 2 as a "square panel" and to the panel of Fig. 3 as a "rectangular panel".

The detailed construction of the panels of Figs. 2 and 3 will be sufficiently indicated for the purposes of the present invention by the fragment of the panel of Fig. 3 which is shown enlarged and less diagrammatically in Fig. 4. On the panel back are mounted adjustable mutual in-

Each inductance unit stands on a square bakelite base such as 42 in Fig. 4, 42 carrying at each of its corners a pair of soldering lugs such as 43. The intersections of the pairs, such as 3—11 of Fig. 3, occur on these bases 42 which carry the soldering lugs such as 43. Centrally mounted on each base 42 is the adjustable mutual inductance indicated generally in Fig. 4 and shown more in detail in Fig. 5. In the two sides of the pair from 45 to 46 are the respective coils 48 and 49 with their common axis perpendicular to the panel face. The sides of the other pair from 43 to 44 are twisted together with excess of length to facilitate adjustment, but at the midpoint between the soldering lugs 43 and 44, one side of this pair goes through the coil 50 which is mounted so that it is coaxial with coils 48 and 49 and adjustable along the common axis by means of the handhold 47.

The inductance units on the bases 42 occupy only about half the space of the panel. Alongside each base 42 is a space 51 of about the same size in which is mounted an adjustable mutual capacity unit comprising the stacks of fixed plates 52 and 53 connected respectively to the sides of one pair at soldering lugs 44 and the stack of movable plates 54 connected to one side of the other pair at one of the soldering lugs 46. Adjustment may be made by application of a screw-driver at 55.

At successive intersections along one pair, the two fixed coils 48 and 49 alternate with the one movable coil 50, and at successive intersections where movable coils appear on the same pair, they are connected alternately in one side and then the other of that pair. To keep the characteristic impedance of the line substantially unchanged by these series coils, suitable fixed condensers are connected across the pairs at regular intervals of not less than about five and not more than about twenty intersections along each pair. These condensers are in rows extending across the panels parallel with the edges which carry the terminals.

Fig. 6 is a semi-diagrammatic view representing a segment of a cable 60 in which most of the pairs extend through directly from right to left, but a complement, of say 20 pairs, coming in from the left is taken off through the branch cable 61 to the square panel 1 (like Fig. 2) whence the pairs are gathered together in the branch cable 63 and go on to the right in the cable 60.

Suppose that at a later time it is desired to balance or compensate another complement of pairs in the same cable 60. The same panel 1, previously installed, is shown in Fig. 7, and in addition another complement is taken out through the branch cables 61' and 63' and through the square panel 2 which is like the square panel 1. Thus, in the panels 1 and 2, each pair of complement 1 may be balanced against each other pair of that complement, and each pair of complement 2 may be balanced against each other pair of that complement. Both panels 1 and 2 are of the type shown in Fig. 2.

It remains to provide for balancing each pair of complement 1 with each pair of complement 2. This is done in the third panel 1/2. The branch cables 61'' and 63'' carry all the pairs of both complements 1 and 2; the panel 1/2 is a rectangular panel like that shown in Fig. 3, with provision for balancing each pair of complement 1 against each pair of complement 2.

The systems of Figs. 6 and 7 are represented again according to a somewhat different schematic in Figs. 8 and 9, respectively. The six parallel lines in Fig. 8 represent six complements of a cable, each of which may be thought of as consisting of twenty pairs. In Fig. 8 one of these complements, which may be called complement 1, is taken out through a square panel as has been explained more in detail for Fig. 6. At a later time as in Fig. 9 complement 2 is also taken out through a square panel 2, and at the same time both complements are taken out through the rectangular panel $\frac{1}{2}$, as has been explained more in detail for Fig. 7. Whatever the number of pairs in the first complement, say twenty pairs for example, the number of pairs must be the same in each succeeding complement.

The cable 60 of Figs. 6 and 7 may be carried through a little house at midsection between repeater stations; in this house the panels will be arranged systematically according to the plan set forth herein in connection with Figs. 6 to 17. If the cable 60 is carried on poles, each panel may be placed in a weatherproof sheet metal box mounted on a pole. As more panels are added according to the plan of Figs. 6 to 17, more poles may be set up for them between those already occupied by panels, or the earlier panels may be distributed along the poles so as to leave intermediate poles vacant of panels in the earlier stages, where such panels may be placed in the later stages. Thus in Fig. 12 the fifteen panels of that figure may be thought of as mounted on fifteen consecutive poles present from the outset for support of the cable. Although it is here suggested that the plan of Figs. 8 to 17 may be thought of as practiced by setting the panels up on respective poles of a pole line, this plan may be practiced otherwise, as by setting the panels up in an inclusive housing associated with a repeater station or in such a housing at a place between repeater stations.

The cable sheath may contain nitrogen under sustained pressure according to well known practice. To prevent this nitrogen from leaking out of the cable where the panels are installed, a plug splice is provided in the cable branch 61—63 leading to the panel. The panel box or casing may be filled with nitrogen under less pressure than that in the cable. If this is done, each such panel casing is provided with a safety valve which permits the escape of the nitrogen at moderate pressure. If there should be any leakage of nitrogen from the cable sheath into the panel box, this safety valve prevents the pressure from building up in the box. The boxes for the square panels, each carrying twenty pairs, may be about $3\frac{1}{2}$ feet square. The corresponding boxes for the rectangular panels may be about $3\frac{1}{2}$ by 7 feet, or two $3\frac{1}{2}$ foot square boxes may be set side by side with half the rectangular panel in each box, the two halves joined by a short length of connector cable.

The order of arrangement of the three panels 1, 2, and $\frac{1}{2}$ of Fig. 7 preserves and extends a feature of construction that is embodied in the two types of panels, square and rectangular, that have been considered. Each of these panels has the advantage that one way along each of two pairs, from where corrective connection is made between those two pairs, there will be about the same number of such corrective connections on one pair as on the other pair. The same is true the other way from where the correction is made. For example, in Fig. 2, reading from top to bot-

tom with reference to the intersection 1—5, there are three preceding intersections along pair 1, and two preceding intersections along pair 5. On any square panel of the kind shown in Fig. 2, the number of intersections along two pairs preceding their intersection will not differ by more than a unit. The same principle is exemplified in the rectangular panel of Fig. 3. For example, along the pair 5 preceding the intersection 5—7 there are four intersections; and along the pair 7 preceding that same intersection there are four intersections. Similarly, the intersections are the same in number the other way from the common intersection; for example, there is one intersection on each of the pairs 5 and 7 below the intersection 5—7. The advantage of the relation pointed out is that the cumulative phase shift such as it may be, due to corrective connections, will be about the same along each pair to the point where the corrective connection is made between these pairs. Accordingly, the corrective connection between these two pairs will be effective alike for crosstalk either way; whereas if the number of corrective connections preceding the point mentioned were substantially different along one pair from what it is along the other pair, the resultant difference of phase shift would at best make the correction a matter of compromise.

According to the present invention, the individual panels, square and rectangular, are designed to satisfy the principle that has just been explained, namely, that the number of intersections along one pair going one way from its intersection with another particular pair shall be the same or differ by not more than unity, going the same way along that other pair.

Referring to Fig. 9 it will be seen that within the group *a* of panels stretching along the cable, each pair appears on a panel once and only once, and within the like group *b* each pair appears on a panel once and only once. Within the group *a* each pair intersects nineteen other pairs, and within the group *b* each pair intersects twenty other pairs. Thus, it will be seen that within the combined groups *a* and *b* the number of intersections preceding (or succeeding) a particular intersection, will be the same along one of the pairs of that intersection as along the other pair of that intersection.

This principle will be exemplified more conspicuously in the figures that follow.

The wide spacing in Fig. 9, between the panel 2 and the panel $\frac{1}{2}$, is intended to facilitate taking out further complements from the cable at later times and carrying them across panels without disturbing the preceding panels, and yet preserving the principle that has been discussed heretofore.

In Fig. 10 a third complement is taken out and carried across the square panel 3 thus providing intersections between each pair of complement 3 and each other pair of that same complement. The two rectangular panels $\frac{1}{2}$ and $\frac{2}{3}$ are also provided, and all these panels are distributed along the cable as shown in Fig. 10. Complements 1 and 3 are taken out to panel $\frac{1}{2}$ and complements 2 and 3 are taken out to panel $\frac{2}{3}$. Thus, it will be seen that in one or another of the six panels shown in Fig. 10 each pair has one and only one intersection with any one other pair. Also, the principle is preserved that along any two pairs, one way from their point of intersection, there is the same number of intersections on each. Three groups are shown in Fig. 10, 75

namely, *a*, *b*, and *c*. Each pair appears on a panel once and only once in each group.

A fourth complement is taken out as shown in Fig. 11, and carried across the square panel 4, and three additional rectangular panels are also added in Fig. 11 to bring each pair of the fourth complement to intersection with each pair of the preceding complements 1, 2 and 3. Here it will be noticed that the panels fall in four consecutive groups such that within each group each pair appears only once on a panel. Within each group each pair passes through either nineteen or twenty intersections, according as its appearance is on a square or rectangular panel.

It will be seen that the successive transitions from Fig. 8 through Figs. 9 and 10 to Fig. 12 have been made in such a way as to leave spaces for the addition of panels without disturbing the existing panels, and so that at each stage the panels will fall in successive groups as explained heretofore. In Fig. 12 five complements appear on the panels and these panels lie in five groups, *a*, *b*, *c*, *d* and *e*.

Consider, for example, two pairs of Fig. 12 which intersect in the panel $\frac{3}{4}$, and, more particularly, consider one of these pairs in the complement 2. Going from left to right this pair appears, and is intersected twenty times in panel $\frac{3}{4}$, twenty times in panel $\frac{1}{2}$ and nineteen times in panel 2, fifty-nine times in all, before reaching the panel $\frac{3}{4}$. The other member of the pair considered, belonging to the complement 4, is intersected twenty times in panel $\frac{1}{4}$, twenty times in panel $\frac{3}{4}$, and twenty times in panel $\frac{1}{2}$, sixty times in all, before reaching the panel $\frac{3}{4}$. These numbers, fifty-nine and sixty, differ by only one. They will always be either equal or different by one. Going on to the right from the panel $\frac{3}{4}$, the pair in complement 2 intersects twenty other pairs in panel $\frac{1}{2}$, and the pair in complement 4 intersects nineteen other pairs in panel 4. And, as explained heretofore, the number of intersections within the panel $\frac{3}{4}$ is almost, or quite, the same along one of the two pairs considered as along the other.

According to the plan of spacing the panels for Figs. 8 to 12, the system is filled up with the inclusion of the fifth complement in Fig. 12. If another complement were to be included and preserve the principle of successive groups with one complete appearance of each and every pair within each group, the panels of Fig. 12 would have to be shifted and spaced out, requiring the breaking and remaking of a considerable number of cable connections.

Figs. 13 to 17 are highly diagrammatic representations indicating how the system might be carried on to the successive inclusion of ten complements. Fig. 13 presupposes a different wider spacing from that followed in Figs. 8 to 12. In Fig. 13 each integral number, like 6 or 5, represents the corresponding square panel, and each fraction like $\frac{1}{4}$ or $\frac{3}{4}$ represents the corresponding rectangular panel.

I have not found it practicable to plan an arrangement at the outset by which all the panels installed for seven complements may be left in place upon the inclusion of the eighth complement. According to the plan which leads to Fig. 13 and continues on through Fig. 17, the rectangular panel $\frac{1}{2}$ is taken from the place it has occupied until after the inclusion of the seventh complement and shifted to another place for the inclusion of the eighth complement, as will be seen clearly by comparing Figs. 14 and 15. Sim-

ilarly, to make the transition from Fig. 15 to Fig. 16 which corresponds to including the ninth complement of pairs, two more shifts are necessary, namely, of square panel 5 and rectangular panel $\frac{3}{4}$. And, to pass from Fig. 16 to Fig. 17 upon the inclusion of the tenth complement, yet two more shifts are necessary, namely, panels 6 and $\frac{1}{4}$, as shown by a comparison of those figures.

I claim:

1. A plurality of neighboring conductor pairs grouped in complements, panels for the respective complements on which each pair of the complement intersects each other pair thereof, and other panels for the respective pairs of complements on which each conductor pair of one complement intersects each conductor pair of the other complement, said panels being disposed along the said plurality of conductor pairs in successive groups in each of which groups the number of intersections is substantially the same along each pair of all the complements.

2. The method keeping the phase shift about the same in each of two pairs of signaling conductors carried across successive panels on which they are subjected to phase disturbing adjustments at intersection points of each pair with each other pair, which consists in carrying the said two pairs across the panels with the same number of intersections along each pair to the intersection of the members of the said two pairs, and carrying the conductor pairs to the panels in successive groups of panels with each appearing on one and only one panel in a group of panels.

3. In combination, a cable comprising a number of conductor pairs grouped in complements, a plurality of panels of each of two kinds in definite order beside the cable, a single complement being carried across a panel of one kind so that each pair thereof intersects each other pair thereof, each pair of complements being carried across a respective panel of the other kind so that each conductor pair of one complement intersects each conductor pair of the other complement, the intersections on each panel and the panels in relation to one another being disposed so that proceeding one way along the cable along any pair of conductor pairs from their intersection there will be the same number of intersections along each of the two conductor pairs, and proceeding in the opposite direction from their intersection there will be the same number of intersections on each conductor pair.

4. In combination with a cable comprising a number of conductor pairs between each two of which a phase-disturbing cross-talk adjustment is to be made, a plurality of panels of one kind across each of which a respective complement of said conductor pairs is carried so that each pair of the said complement intersects each other pair thereof, a cross-talk adjuster at each of said intersections, a plurality of panels of another kind across each of which a respective pair of said complements is carried so that each conductor pair of one of said pair of complements intersects each conductor pair of the other of said complements, a cross-talk adjuster at each of said last-mentioned intersections, all of said panels being arranged in circuit successive groups along said cable so that in each group each complement appears once and only once.

5. A combination in accordance with the claim next preceding in which in both circuit directions from any of said cross-talk adjusters there is substantially the same number of adjusters along

the two circuit pairs intersecting at said adjuster.

6. In a cable system, a multiplicity of conductor pairs grouped in three or more complements, means individual to said complements for effecting a compensating coupling between each pair of the complement and every other pair of the complement, means individual to each pair of said complements for similarly effecting a compensating coupling between each conductor pair of one complement and each conductor of the other complement, all of said means being disposed in such circuit sequence that along any two of said conductor pairs there are substantially the same number of couplings up to the point where they are coupled together.

7. At a cross-talk correcting point in a cable system, a multiplicity of complements of conductor pairs, panels of a first kind on which only intra-complement correction is effected, panels of a second kind on which only inter-complement correction is effected, said panels of both kinds being grouped in such circuit sequence that in each group each complement appears once and only once.

8. A combination in accordance with the claim next preceding in which each conductor pair is brought into corrective relation with another conductor pair only at points where both pairs have been involved in substantially the same number of corrective relations.

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