July 22, 1924. **1,501,959**

W. H. MARTIN ET AL

LOADED TRANSMISSION CIRCUITS

Original Filed June 30, 1922 4 Sheets-Sheet 1

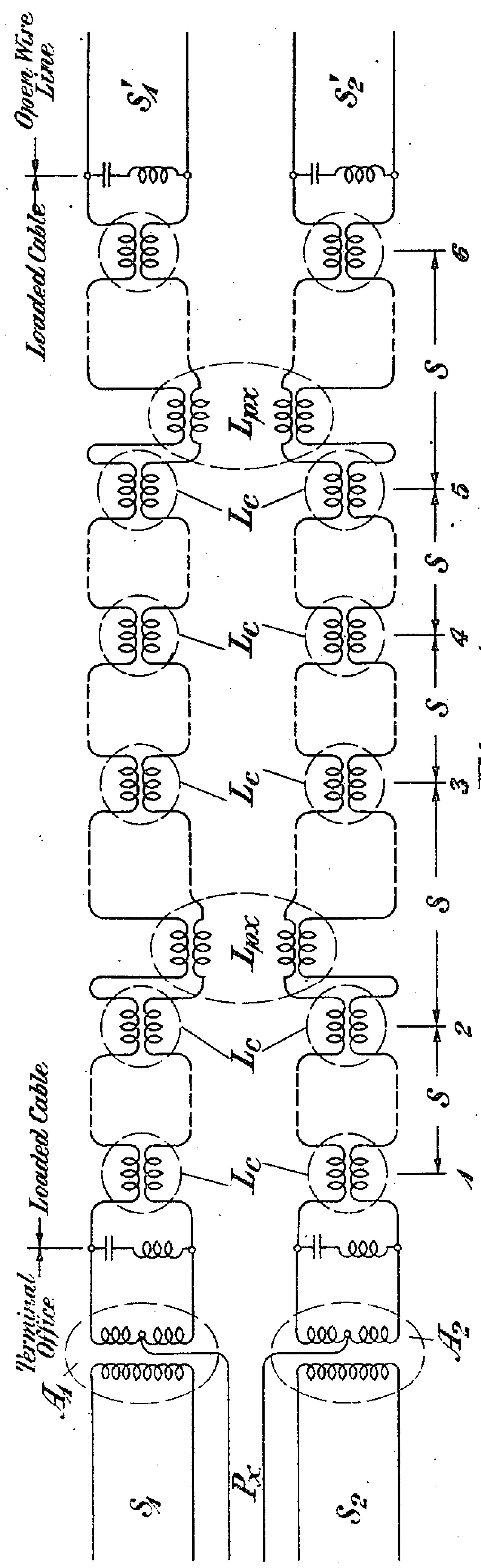

Fig. 1

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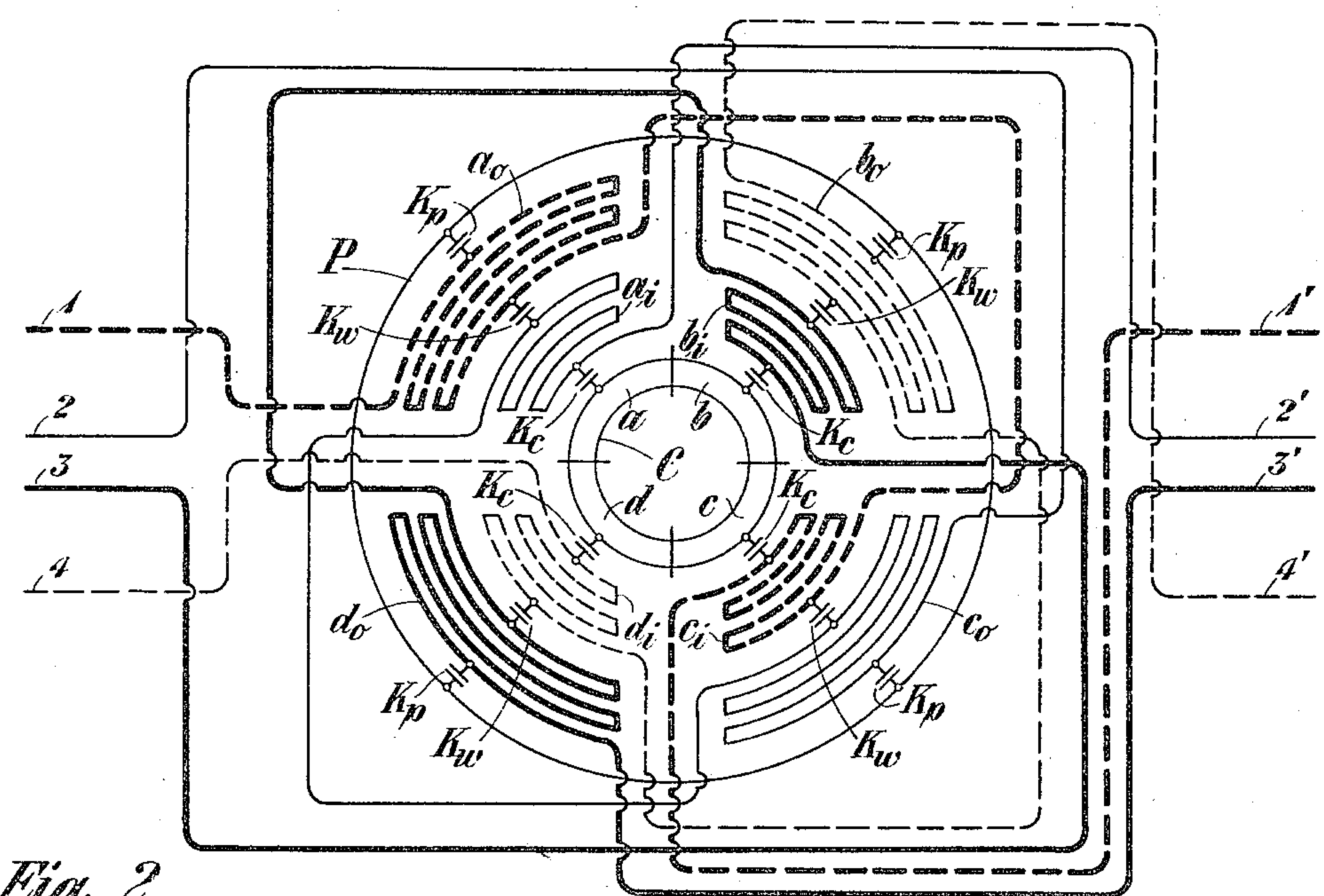

Fig. 2

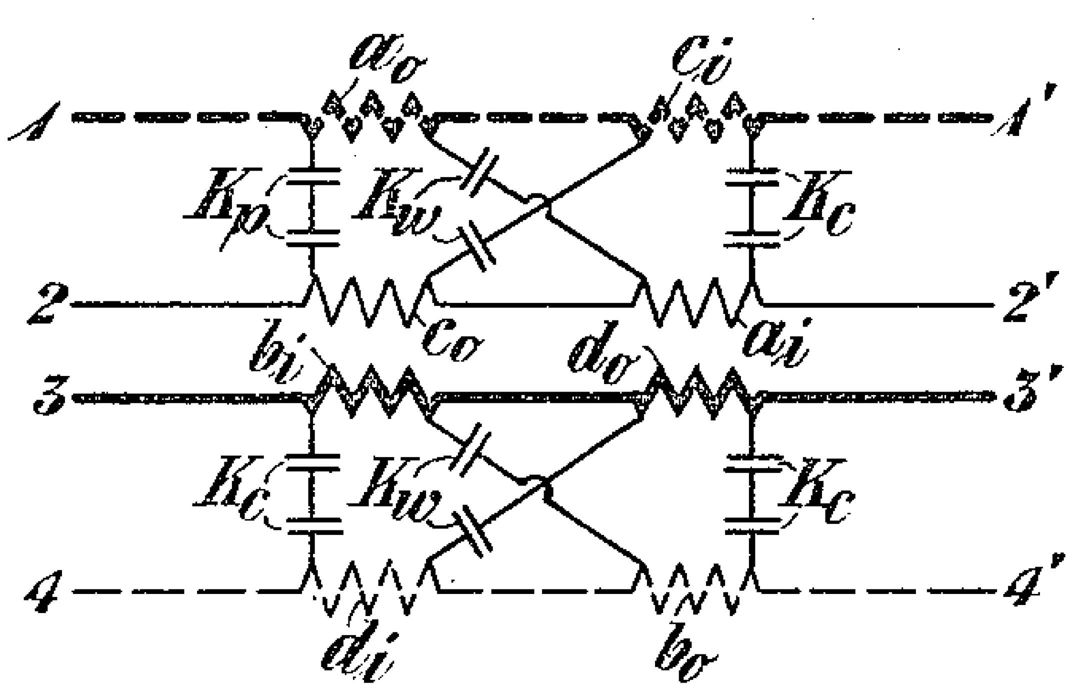

Fig. 3

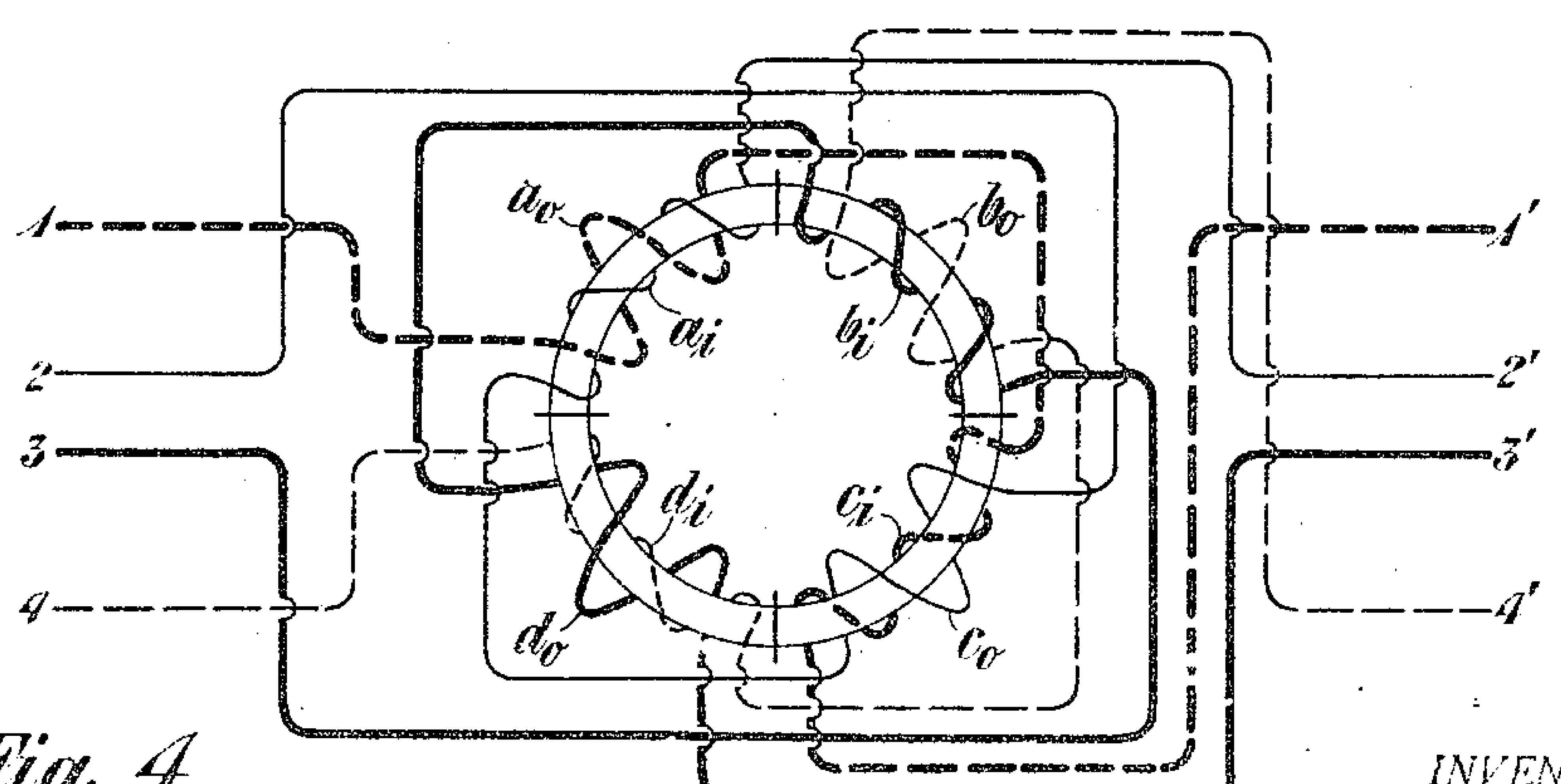

Fig. 4

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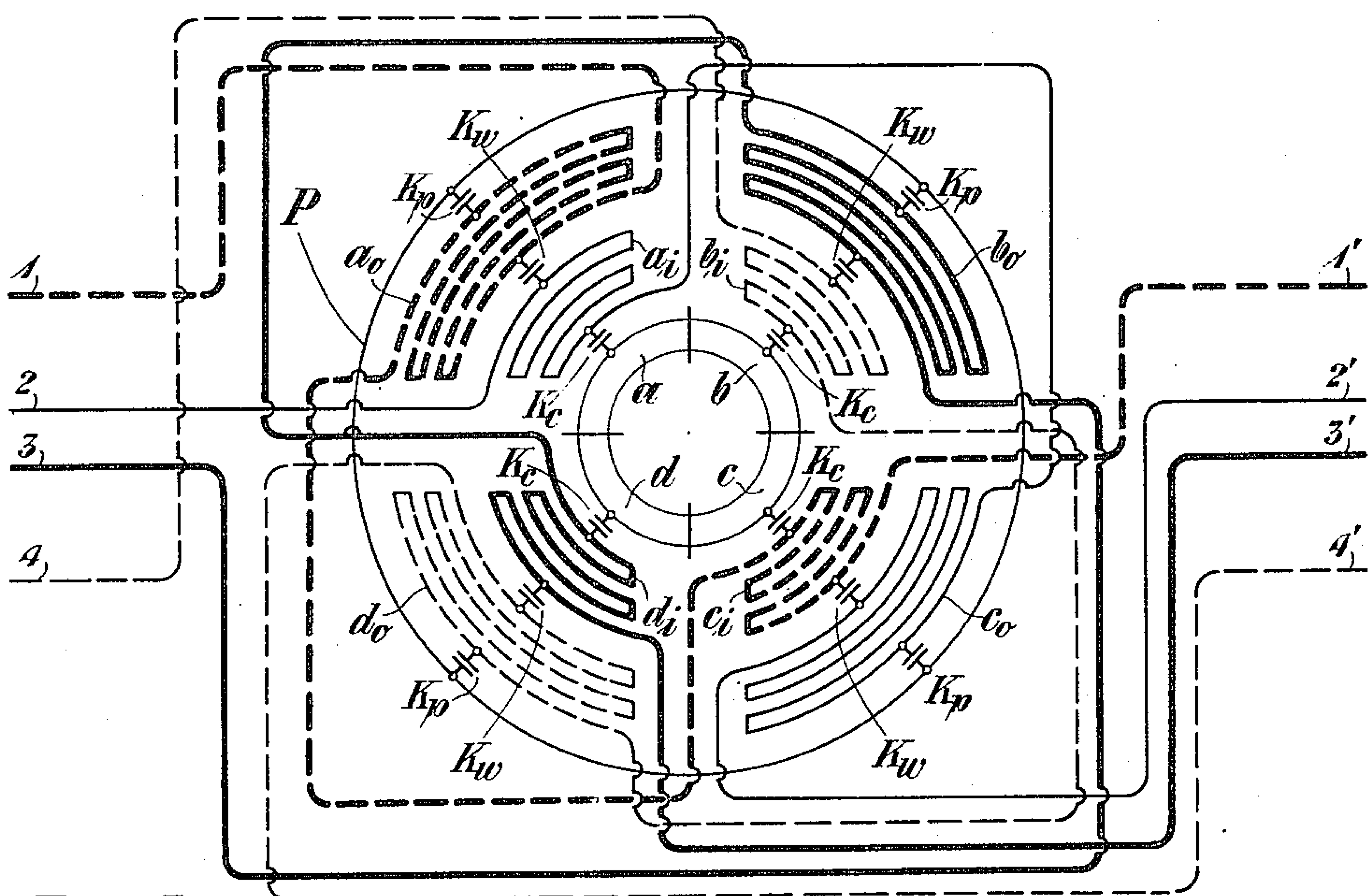

Fig. 5

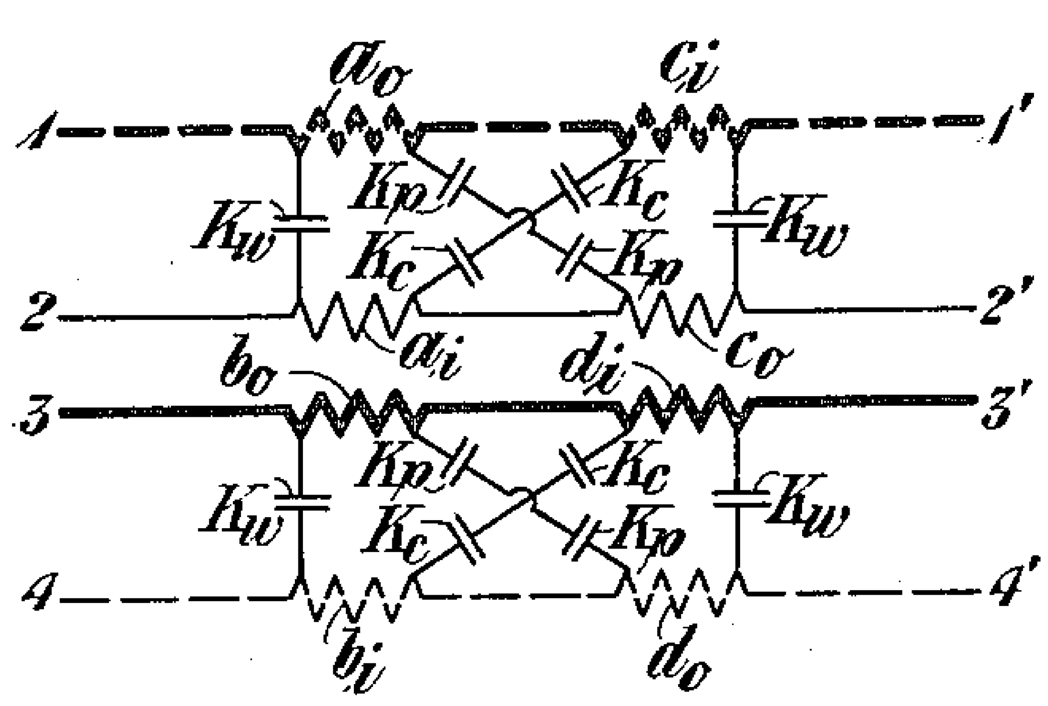

Fig. 6

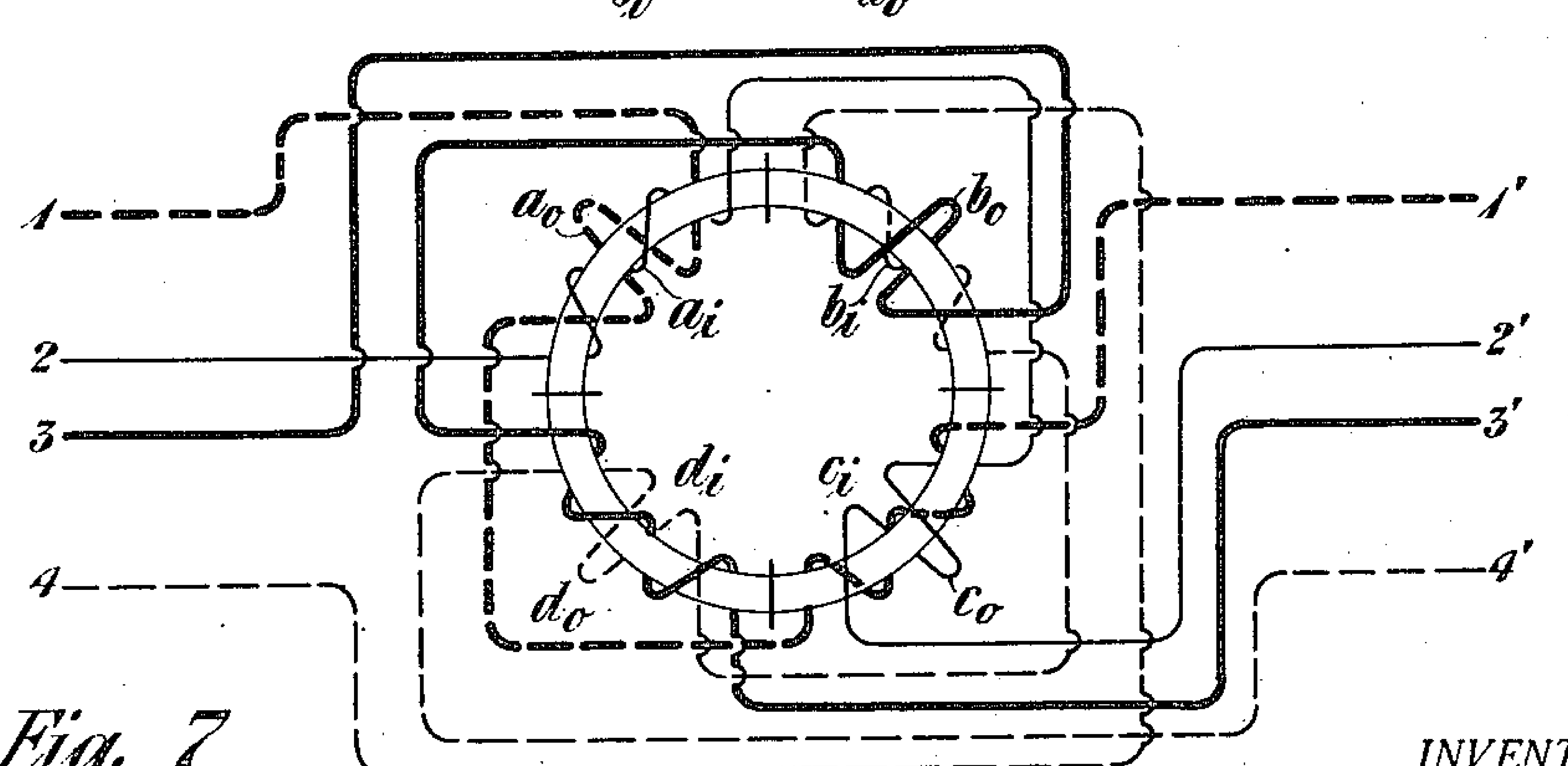

Fig. 7

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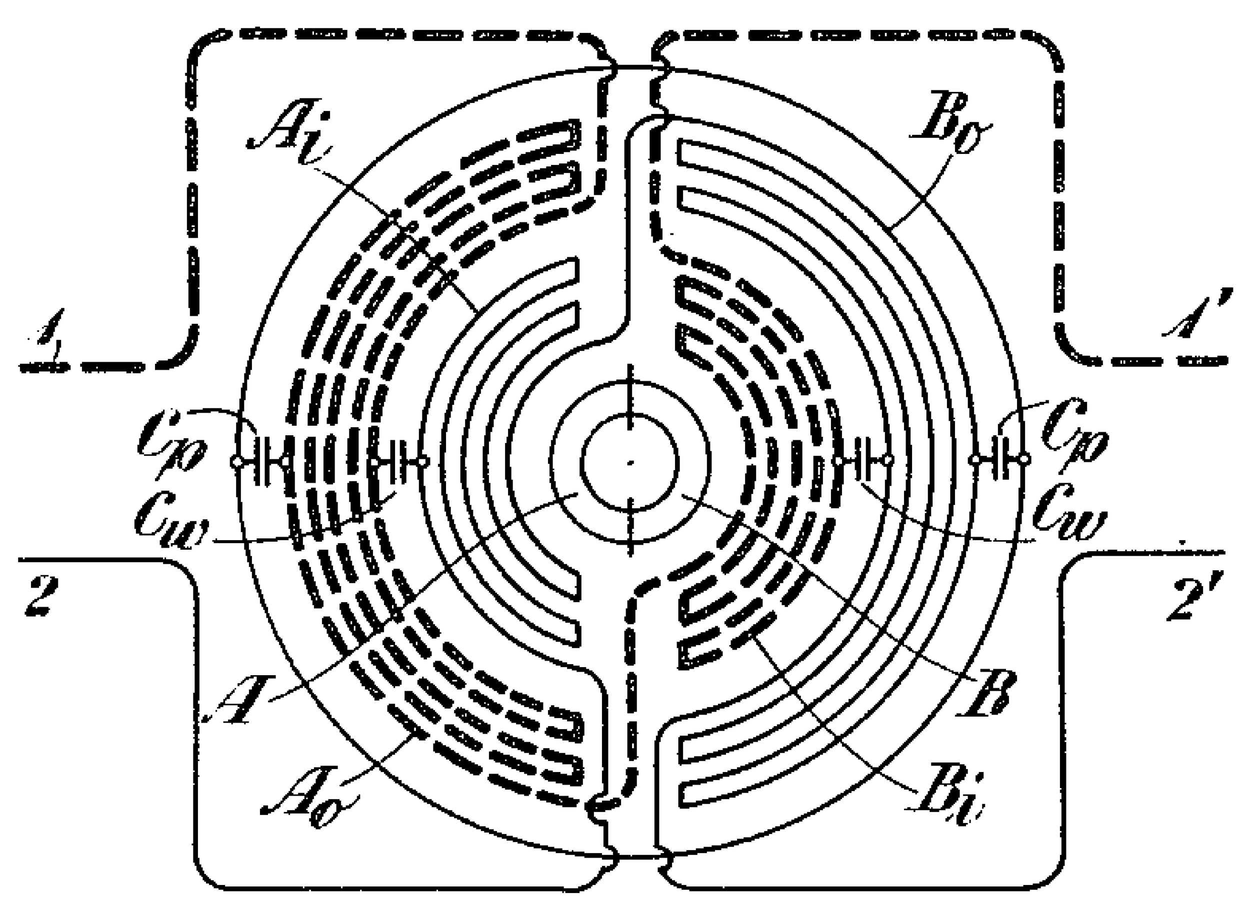

Fig. 8

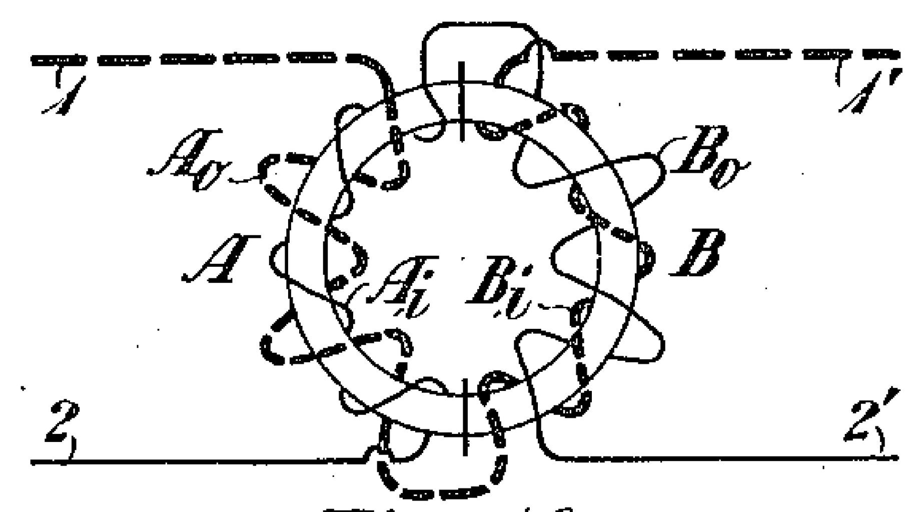

Fig. 10

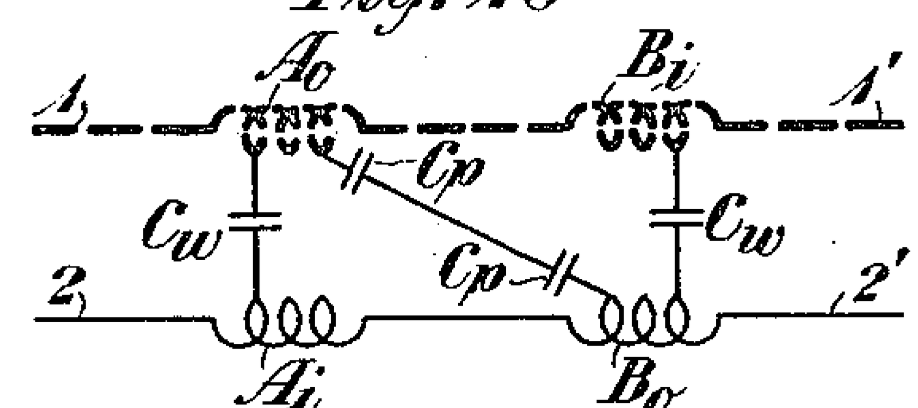

Fig. 9

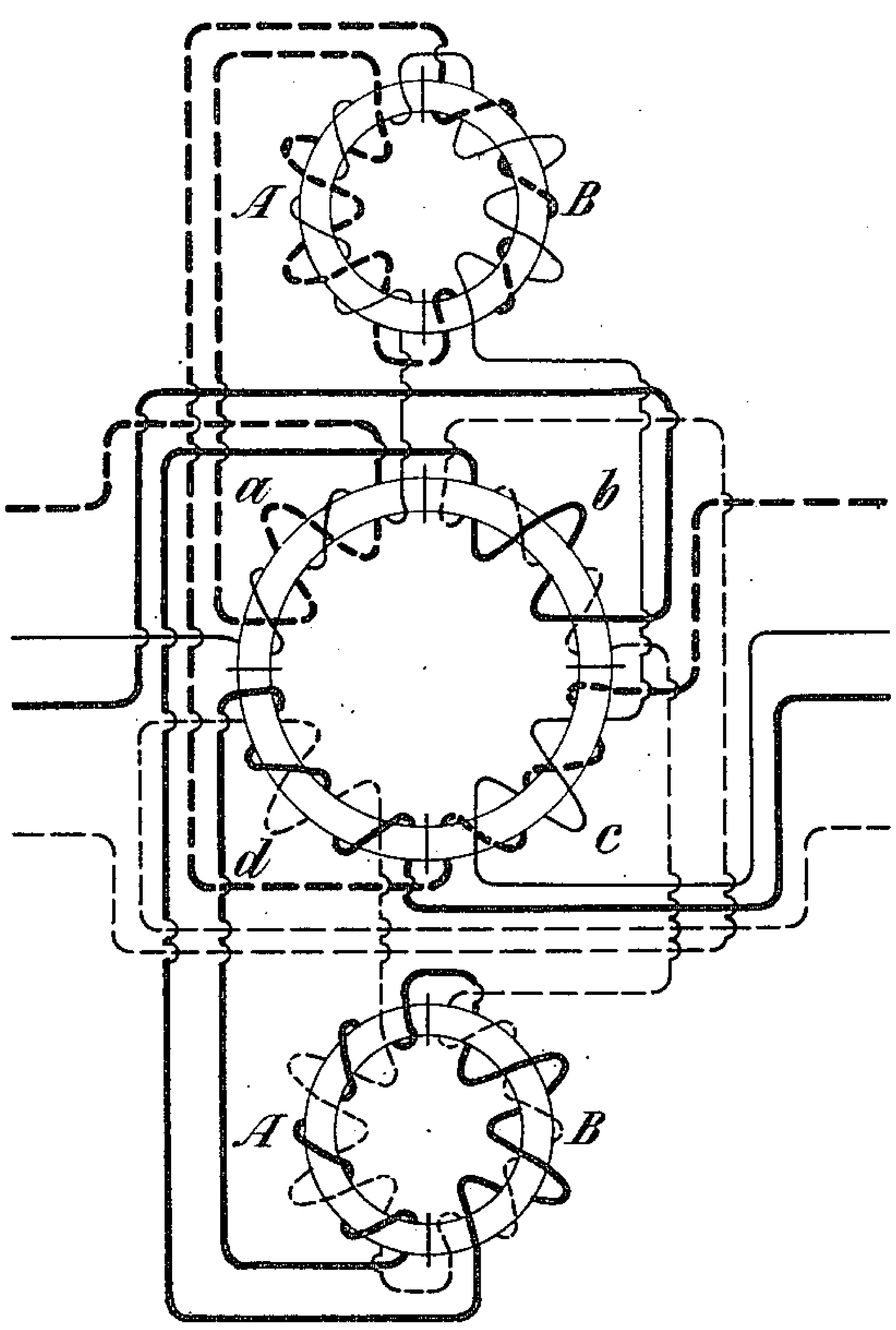

Fig. 11

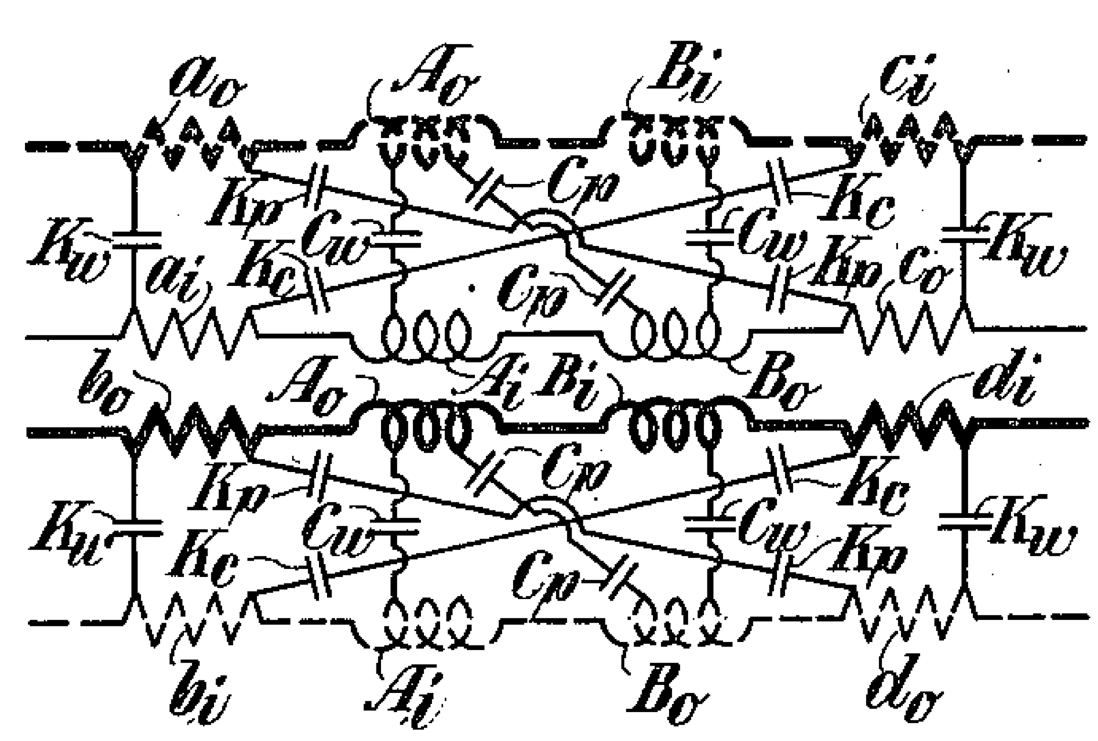

Fig. 12

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Patented July 22, 1924. **1,501,959**

UNITED STATES PATENT OFFICE.

WILLIAM H. MARTIN, OF NEW YORK, N. Y., AND THOMAS SHAW, OF HACKENSACK, NEW JERSEY, ASSIGNORS TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

LOADED TRANSMISSION CIRCUITS.

Application filed June 30, 1922, Serial No. 571,893. Renewed November 22, 1923.

To all whom it may concern:

Be it known that we, WILLIAM H. MARTIN and THOMAS SHAW, residing at New York and Hackensack, in the counties of Bronx and Bergen and States of New York and New Jersey, respectively, have invented certain Improvements in Loaded Transmission Circuits, of which the following is a specification.

This invention relates to the loading of transmission circuits, and more particularly to the loading of transmission circuits which are to be employed for the transmission of carrier frequencies.

In multiplex systems employing carrier frequencies for transmission purposes, it has been found that open-wire lines are best adapted for transmission of carrier frequencies, and, in general, cable circuits of considerable length cannot be employed for this purpose, because the capacity and resistance of the cable tends to greatly increase the attenuation of the higher frequencies. In the practical layout of a plant employing carrier transmission, however, the use of some cable lengths in a given circuit cannot well be avoided by reason of the fact that cable is used in entering practically all large cities and is used for terminal purposes.

The resistance, inductance, capacity and conductance, respectively, of a cable, are inherently different from those of open-wire line. In consequence of these differences, the presence of cable in an open-wire line circuit causes impedance irregularities at the junction points of the cable and the open-wire line. These irregularities are transmitted to the telephone repeaters and cause reduction in the gain of the repeaters. These irregularities also cause reflection losses and transmission distortion.

The impedance irregularity may be approximately eliminated by loading the inserted cable so that it has as nearly as possible the same characteristic impedance as the open-wire line with which it is associated. In doing this the loading coil inductance and the spacing of the coils should be so chosen that the loaded cable circuits will transmit efficiently the different carrier frequencies which are transmitted over the open-wire line.

As is well known, it is common practice to obtain three telephone circuits from each group of four wires by using each of two pairs of wires as a side circuit and by using the two pairs together as a phantom circuit. In the application of carrier transmission to telephone circuits of this type, however, it is not expedient to use phantom circuits for carrier telephone and telegraph transmission systems because of crosstalk difficulties which would be encountered. Carrier systems are only superposed on physical circuits (that is, pairs of wires which are not phantomed) or on the side circuits of phantom groups. Consequently, where, as is usually the case, a phantom group includes cable in the open-wire circuit, it is desirable to load the side circuits to a cut-off frequency sufficiently high to transmit the carrier frequencies ordinarily used, while loading the phantom with the usual lower cut-off loading employed in connection with ordinary voice transmission.

While it would be a relatively simple matter to load these circuits, if the side circuits and the phantom circuit of a group were all loaded alike, the loading of the phantom for one cut-off frequency and the side circuits for a higher cut-off frequency involves considerable difficulty. The expedient of loading the phantom to the same cut-off frequency as the side circuits is not practicable because the number of loading coils per unit length increases with the frequency of the cut-off frequency, and to load the phantom with the additional coils necessary to bring it up to the same cut-off point as the side circuits would be extremely expensive when it is considered that no additional transmission channels would be obtained from the phantom by the extra loading.

Carrier systems as now operated require efficient transmission of frequencies up to approximately 30,000 cycles. In order to obtain satisfactory transmission and impedance characteristics in the entrance and intermediate cables through which carrier systems are routed, it is necessary to space the loading coils at a relatively close spacing of approximately 900 feet. On the other hand, in connection with the transmission of ordinary speech through cables inserted in open-wire lines, very satisfactory results are obtained by spacing loading coils at intervals of about 5,600 feet.

In view of the fundamentally different transmission requirements of carrier circuits superposed on the sides of phantoms and the ordinary speech channel over the phantom circuit itself, it is convenient and economical to load each transmission circuit system with independent sets of coils spaced at approximately the intervals above mentioned. In practice, it has been found that six loading coils inserted in the carrier side circuit for each loading coil inserted in the voice frequency phantom satisfies the transmission requirements above referred to and at the same time conforms to the exigencies of the ordinary plant practice.

The use of two different sets of coils for the carrier circuit and the phantom circuit loading involves certain difficulties in that the phantom circuit loading coils add certain effects to the carrier circuits which should be properly allowed for in the design of the loading, in order to obtain satisfactory transmission and impedance characteristics in the carrier circuits. Correspondingly, the effects of the carrier circuit coils on the phantom circuit should be allowed for in the phantom circuit loading design.

It is one of the objects of the invention to provide a loading unit to be employed at the phantom loading point of a system in which the side circuits are loaded for carrier frequencies and the phantom for ordinary voice frequencies, the loading unit being so designed as to provide the proper loading effect both for the phantom and for the side circuits.

The manner in which this object, as well as other objects of the invention, is attained may be understood from the following detailed description of the invention, when read in connection with the accompanying drawings, in which Figure 1 is a schematic layout of the loading of a section of cable intervening between the terminal office and a phantom group of an open-wire line; Fig. 2 is a diagram showing the layer arrangement of the windings of an ordinary phantom loading coil; Fig. 3 is a diagram showing the capacity distribution of the windings of the phantom loading coil of Fig. 2; Fig. 4 is a diagram showing the magnetic relation of the windings of the phantom coil of Fig. 2; Fig. 5 is a diagram showing the layer formation of the windings of the phantom coil of the loading unit employed in connection with the present invention; Fig. 6 is a diagram showing the capacity distribution of the phantom coil of Fig. 5; Fig. 7 is a diagram showing the magnetic relation of the windings of the phantom coil of Fig. 5; Fig. 8 is a diagram showing the layer formation of the windings of a side circuit coil to be employed in the loading unit of the present invention; Fig. 9 is a diagram showing the capacity distribution of the coil of Fig. 8; Fig. 10 is a diagram showing the magnetic relation of the windings of the coil of Fig. 8; Fig. 11 is a diagram showing the magnetic relation of the complete loading unit of the present invention, and Fig. 12 is a diagram showing the capacity distribution of the loading unit shown in Fig. 11.

As has already been described and as is illustrated in the drawing, the phantom loading coils L_{px} occur much less frequently than the carrier circuit loading coils L_c. In the drawing, S_1 and S_2 represent the side circuit drops at the terminal office, and S_1' and S_2' designate the corresponding open-wire connections terminating at some point outside of the office. In the circuits S_1 and S_2, phantom terminating transformers A_1 and A_2 are inserted, and taps are taken from the midpoints of the coils of these transformers to form the phantom drop P_x. Intervening between the terminal office and the terminals of the open-wire circuits S_1' and S_2' are a number of loading points numbered from 1 to 6 inclusive. These loading points are preferably equally spaced, the spacing between two adjacent loading points being designated on the drawing as S. Side circuit coils L_c are included in each side circuit at each of the loading points indicated, and in addition phantom coils L_{px} are included at the loading points numbered 2 and 5. Thus it will be seen that, as illustrated in the circuit shown, there is one phantom coil for every three side circuit coils. This number has been chosen in order to simplify the illustration in the drawing, but it will be understood that in actual practice, where the carrier range extends to a frequency in the neighborhood of 30,000 cycles, a greater number of side coils will occur for each phantom. Six side circuit coils to each phantom circuit coil have been found to be a satisfactory number, as has already been stated.

Considering first the reactance of phantom loading upon the carrier circuit loading installed on the side circuits, it will be obvious that owing to the fact that the phantom loading coils occur much less frequently than the side circuit loading coils, the resistance, inductance and capacity effects which the phantom loading coils add to the side circuit tend to cause impedance irregularities. The conductance effects of the phantom coils upon the side circuits are negligible.

The coil resistance effects may be minimized by designing the coils so as to obtain as low a resistance as is economically practicable in meeting the other electrical requirements. The inductance added to the carrier circuit by the phantom coils due to magnetic leakage in the coils is, however, a somewhat more serious problem. This may be compensated for by making special adjustments in the carrier circuit loading coil, which is installed at the phantom loading point. In the design of the phantom coil, as will be pointed out later, the capacity effects of the coil are of primary importance, and hence the leakage inductance of the phantom coil must, to a large extent, be permitted to attain whatever value is determined by capacity considerations. The carrier circuit loading coil installed at the phantom loading point as noted above is designed to have an inductance smaller than the inductance of the other side circuit coils by an amount equal to the inductance of the phantom coil in the side circuit. In this connection it should be noted that general considerations of economy and plant flexibility make it desirable to install the phantom loading coil at the carrier loading points, so that the inductance can be taken care of in the manner stated.

As an example, suppose the loading of the side circuit requires a side circuit coil at each loading point having an inductance of 5.25 milhenrys. Suppose, on the other hand, that the inductance of the phantom coil in the side circuit at the phantom loading points adds .10 milhenry to the side circuit. If it is necessary to bring the side circuit inductance to within one per cent of the figure given above for a side circuit coil, it will be apparent that the inductance added by the phantom involves a greater variation in this section than will be permissible. Accordingly, the inductance in this section may be taken care of, so far as a side circuit is concerned, by providing a coil for the side circuit at this loading point, having an inductance of 5.15 milhenrys, so that the total loading inductance in the side circuit at this point will be 5.25 milhenrys.

The most troublesome irregularity from the standpoint of design is that due to the inherent mutual capacity between the side circuit line windings of the phantom loading coil. As is well known, these windings are interleaved in order to obtain good electrical balance. This balance is necessary in order to avoid objectionable phantom-to-side cross-talk. This construction causes an appreciable direct capacity between the two windings. The windings also have a direct capacity to the case in which the coils are potted and a direct capacity to the loading coil core, which consists of iron.

The manner in which the windings of the usual type of phantom coil are interleaved will be clear from the diagram of Fig. 2. In this diagram, 1, 2, 3 and 4 designate the four conductors of a quad in which conductors 1 and 2 are used for one side circuit and conductors 3 and 4 for the other side circuit, the phantom being formed by conductors 1 and 2 in parallel for current flowing in one direction, and conductors 3 and 4 in parallel forming the return conductor for current flowing in the other direction. The core C of the phantom loading coil has four quadrants, a, b, c and d, and two windings, an inner and an outer winding, are wound upon each quadrant.

The windings wound upon the core are represented in the form of successive layers, beginning with a layer adjacent the core itself and extending to an outer layer adjacent the pot P. For example, the inner windings a_1 has an inner layer adjacent the core quadrant a and its outer layer is adjacent the innermost layer of the outer winding a_0. The outermost layer of the winding a_0 is adjacent the pot P. The windings on the other four core quadrants are similarly shown.

The interleaving of the windings will be apparent from the diagram. As will be seen, each winding included in a side circuit conductor is formed in two halves, one being an outer winding on one quadrant and the other half being an inner winding on the opposite quadrant. For example, conductor 1 is connected to the outer layer of the winding a_0 upon the a quadrant of the core. The inner layer of this winding is connected to the outer layer of the inner winding c_1 upon the c quadrant of the core, and the innermost layer of the latter winding is then connected to the conductor 1′. The other conductor 2 of the same side circuit is connected to the outer layer of the outer winding c_0 upon the c quadrant of the core, an inner layer of said winding being connected to the outer layer of the inner winding a_1 on the a quadrant of the core, the inner layer of the latter winding being connected to the conductor 2′. The interleaving of the windings included in the side circuit conductors 3 and 4 will be apparent from the diagram without further description.

The principal capacities of the phantom loading coil arrangement are also shown in Fig. 2. For example, there will be a capacity designated as K_c between the inner layer of each inner winding and the core C. There will, of course, be substantially no capacities between the other layers and the core, because the outer layers are shielded by the innermost layer. Similarly, there will be a capacity K_w between the outermost layer of each inner winding and the innermost layer of each outer winding. The capacity between other layers of inner and outer windings will likewise be negligible because of the shielding effect of the adjacent layers of the windings upon each quadrant. Finally, there will be a capacity K_p between the outermost layer of each outer winding and the pot or casing P of the coil.

Of these capacities, capacity K_w is ordinarily largest as the adjacent layers of each inner and outer coil lie directly upon each other, whereas the innermost layer of each inner winding is separated from the core by a fairly thick mass of insulation, and the outermost layer of each outer winding is likewise separated from the pot by a considerable air space.

The electrical relations of the several windings and the distribution of these capacities are shown in Fig. 3. In this figure the windings are shown as resistances for the reason that, so far as the side circuit is concerned, the phantom windings, if ideally constructed, would have no inductance and would, therefore, appear as pure resistances. The segregation of the capacity near the inner or outer layer of a given winding is indicated schematically in the diagram by locating the capacity near the terminal convolutions of the resistance in the diagram.

It will be obvious that the capacities above referred to produce a considerable capacity between the conductors of the side circuit at the loading point. It has been proposed to allow for these capacity effects of the phantom loading coil upon the side circuit by treating the phantom coil as the equivalent (so far as capacity is concerned) of a building-out condenser in the side circuit, which is used for carrier purposes. As is well known, it is common practice, where a section is shorter than the normal loading section to shunt a capacity across the terminals of the section at the loading point, the capacity being designed to increase the capacity of the short section to that of a normal section.

While this expedient may be used in installations where the loading sections are irregular because not originally designed for carrier loading, it is desirable from plant considerations that loading sections be made as far as possible of equal length in the original layout of the plant. Consequently, in new cable installations involving carrier loading initially or ultimately, it is desirable, and usually will be practicable, to lay out the cable man-holes to fit the theoretical carrier loading spacing, and it should not be necessary in a plant thus designed to use building-out condensers to equalize the loading section capacity. Under such conditions, the capacity introduced in the carrier circuits by the phantom loading coils constitutes a source of objectionable irregularity. In long cables, the irregularity effects "pile up" at certain important carrier frequencies because of the uniform periodicity of the recurrence of the individual irregularities. For example, in practical loading systems involving six side circuit loading sections to each phantom loading section, and with the particular length of loading sections employed, the phantom coil irregularity effect in the carrier circuit "piles up" at frequencies which are multiples of approximately 11,000 cycles.

It has been proposed, under the conditions above specified, to take care of the effect of the phantom coil capacity in the side circuit in two ways: (*a*) by selecting for the carrier loading sections which contain the phantom loading coils cable circuits which have proportionately lower capacities than the regular carrier loading sections which do not contain phantom loading coils; (*b*) an equivalent reduction in capacity in the carrier loading section which contains the phantom loading coil may be obtained by geographically shortening this loading section. Neither of the above solutions is satisfactory from a plant standpoint, as both solutions require special engineering and testing work in the installation of the cables and interfere with the flexibility of the use of the cable. From transmission, engineering, plant and operating standpoint, it is desirable to have the carrier loading spacing uniform for all carrier loading sections including the phantom loading sections, this being one of the important conditions for obtaining uniform section capacity values in the carrier loaded circuits.

The conditions just mentioned make it desirable to use at the phantom loading points combination phantom loading units consisting of a phantom coil and two side circuit coils which have approximately the same total resistance, inductance and capacity effects in the side circuits as the regular carrier circuit loading coils which are installed at the loading points where phantom loading is not required. In accordance with the present invention, therefore, it is proposed to employ in the special phantom loading unit a very low capacity type of phantom loading coil which is illustrated in the diagrams of Figs. 5, 6 and 7. It is also proposed to combine with this low capacity type of phantom loading coil special carried loading coils of the type illustrated in Figs. 8, 9 and 10, these coils having a lower capacity than regular carrier loading coils employed at non-phantom points by an amount which makes the total side circuit capacity of the combination phantom carrier loading unit approximately equal to that of the regular carrier loading coils. In this combination unit, the special carrier loading coils are adjusted to have an inductance which is lower than that of the regular carrier coils by an amount equal to the leakage inductance which the phantom loading coil adds to the carrier circuits.

The reduction in capacity of the phantom coil may be attained by providing more insulation between the core and the innermost layer of the inner winding on each quadrant, thus reducing the capacity designated in Figs. 2, 3, 5 and 6 as K_c. More insulation and greater separation will also be provided between the adjacent layers of the inner and outer windings, thereby reducing the capacity K_w which, as already stated, is the principal capacity between the side circuit conductors introduced by the phantom loading coil. The capacity K_p may also be reduced by increasing the space between the outer layer of each outer winding and the pot or casing. These expedients, of course, involve similar reduction of the winding space and hence require the use of smaller gauge conductors in the windings in order to get the desired amount of inductance in the available winding space.

However, it is not sufficient merely to have an equality of capacity between the special combination carrier-phantom loading units and the regular carrier circuit coils. In order to simulate the regular coils from the capacity standpoint, it is desirable also that the capacity distribution in the combination unit should be similar to the distribution of capacities in the regular carrier circuit coils; that is, the capacity distribution should be substantially symmetrical and the largest direct capacities between the conductors of the side circuit should be located near the effective line terminals of the unit.

The problem then is to so design the phantom loading unit that the capacity between the side circuit conductors due to the phantom coil will be distributed in substantially the same manner as the capacity in a side circuit coil. Fig. 8 shows the layer arrangement of the windings in a side circuit coil, and Fig. 9 shows the distribution of the capacities. The core of the side circuit coil where the side circuit is loaded for carrier transmission will be of wood or other nonconducting material of low permeability, so that there will be no capacity between the core and the innermost layers of the inner windings. The capacities C_w between the adjacent layers of the inner and outer windings will be comparatively large and a smaller capacity C_p between the outer layers and the pot will also occur, as indicated in Fig. 8. As shown in Fig. 9, the capacities C_w are effectively connected near the line terminals of the windings. The capacities to the pot are effectively connected adjacent to the inner terminals of the windings A_o and B_o. As a first approximation, they can be considered to constitute a capacity shunt across the circuit, connecting the mid points of the two line windings. Fig. 10 shows the magnetic relation of the windings. It will be observed that all of the windings are wound about the core in the same direction and the connections are such that for currents flowing serially over conductor 1 and back over conductor 2, the flux due to the coils will be aiding. This corresponds to the condition when currents are transmitted in talking over the side circuit. For currents transmitted in parallel over the conductors 1 and 2, the inner and outer windings upon each section of the core are opposing. This corresponds to the condition when talking over the phantom.

If we compare the capacity distribution of the side circuit coil as represented in Fig. 9 with the distribution of the phantom coil capacities in the side circuit as illustrated in Fig. 3, it will be seen that the distribution is quite different. In Fig. 3, the principal capacity is the capacity K_w, which is connected across the side circuit conductors approximately between the mid points of the line windings, while the smaller capacities to the pot and to the core are connected effectively across the windings near the line terminals thereof.

In order to obtain a capacity distribution in the side circuit of the phantom loading unit corresponding to that produced in the side circuit by the regular carrier loading coils, a capacity distribution such as shown in Fig. 6 should be provided in the phantom coil. If we consider the side conductors 1 and 2 in Fig. 6, it will be seen that the capacities K_w, which correspond to the capacity C_w in Fig. 9, are bridged across the coils adjacent the line terminals thereof, and the smaller capacities K_p are bridged across the coils between the mid points of the windings in the same way as in Fig. 9. The smaller capacities K_c between the core and inner layers of the windings are also bridged across the coil circuit between points which are approximately the mid points of the line windings. The capacities K_c are thus effectively in parallel with the capacities K_p. Consequently, we have a condition, so far as capacity distribution is concerned, which very closely approximates that of Fig. 9.

Fig. 5 shows the layer formation of a phantom coil designed to obtain the capacity distribution shown in Fig. 6. Comparing this diagram with that of Fig. 2, which illustrates the ordinary phantom coil construction, it will be seen that in Fig. 5 the line conductor 1 is connected to the innermost layer of the winding a_o instead of to the outermost layer. Likewise, conductor 1′ is connected to the outermost layer of the winding c_i instead of to the innermost layer. The innermost layer of the winding c_i is in turn connected to the outermost layer of the winding a_o. Similarly, the connections to the other windings are transposed as illustrated, and without attempting to point out in detail the various transpositions in connections as compared with Fig. 2, it will be sufficient to state that line conductor 2 is connected to the outermost layer of the winding a_i instead of the outermost layer of winding c_o, and line conductor 2′ is connected to the innermost layer of winding c_o instead of to the innermost layer of winding a_1. Conductor 3 is connected to the inner layer of winding b_o and conductor 3′ to the outermost layer of winding d_o, instead of vice versa, as in Fig. 2. Also, the conductor 4 is connected to the outermost layer of winding b_1 and conductor 4′ to the innermost layer of winding d_o instead of the connections employed in Fig. 2.

The change in connections employed in Fig. 5 is necessitated by the requirements of the capacity distribution shown in Fig. 6, and this involves a reversal of the direction of certain of the windings upon the core in order to obtain the proper magnetic relations, as shown in Fig. 7.

Turning to Fig. 4, which shows the magnetic relations of the windings in the usual type of phantom coil, it will be observed that all of the windings, both inner and outer, upon all four of the quadrants are wound in the same direction but the connections are such that currents flowing in parallel over conductors 1 and 2 and returning over conductors 3 and 4, will produce magnetic fluxes aiding and in the same direction in all four quadrants. A current flowing in one direction, however, in conductor 1, for example, and returning in conductor 2, will produce opposing fluxes in the inner and outer windings of the a and c quadrants, so that if perfect magnetic conditions obtain, there will be no inductance in the side circuit due to the phantom coil.

Comparing this arrangement with Fig. 7 which shows the magnetic relations of the windings necessary to obtain the capacity relations illustrated in Figs. 5 and 6, it will be observed that in Fig. 7 one of the windings on each quadrant, either inner or outer, is reversed with respect to the other. As shown, windings a_o, b_1, c_1 and d_o are wound in the same direction as in Fig. 4. Windings a_1, b_o, c_o and d_1 are wound in the opposite direction to the corresponding windings in Fig. 4. If we consider the fluxes due to currents flowing in parallel over conductors 1 and 2 in one direction and returning over conductors 3 and 4 in parallel, it will be found that the fluxes due to all of the windings on all of the quarants are aiding and in the same direction. The fluxes produced by currents flowing over conductor 1 in one direction and returning over conductor 2, however, will be opposing in the inner and outer windings of a and c quadrants, so that we obtain the same result magnetically in Fig. 7 as in Fig. 4.

As has been previously stated, the phantom coil is to be combined with the side circuit coils at the phantom loading point to produce the desired inductance in the side circuit and obtain the desired capacity relations. In order to secure the desired symmetrical capacity distribution in the loading unit comprising the phantom and two side coils, the side circuit loading coils are inserted in circuit at the electrical center of the line windings of the phantom loading coil, as illustrated in Fig. 12, which shows the resultant capacity distribution. Fig. 11 shows the magnetic relations of the windings of the phantom and two side coils when connected as shown in Fig. 12. This diagram is self-explanatory and no further description is deemed necessary.

In loading units such as is illustrated in Fig. 11, it is also necessary in designing the coils to consider the effects of the carrier circuit loading coils at the various carrier loading points upon the phantom loading. In this connection, however, the capacity effect produced by the side circuit loading coils upon the phantom are of negligible importance as compared with the capacity effects produced by the phantom loading coil upon the side circuit. This is due to two reasons: First, the ordinary phantom speech frequency loading sections have approximately 10 times as much mutual capacity as the ordinary carrier loading sections, thus being in part due to the fact that an ordinary type of phantom circuit has a mutual capacity per unit length which is approximately 60% greater than that of its own side circuits, and in part due to the approximate 6:1 ratio between the physical lengths of the phantom and carrier circuit loading sections; second, the coil mutual capacity effective in the phantom circuit is inherently much less than the coil capacity which is effective in the side circuits. This latter relation will be obvious when we consider that the principal capacity introduced by the side circuit loading coils is between the two conductors of the side circuit, and substantially no capacity is involved between the windings of the coil in one side circuit and the windings of the coil in another side circuit, for the two coils are entirely separate structures and will be located physically a considerable distance apart, as compared with the distance between the two windings of a given side circuit coil. Even the capacity introduced by the phantom loading coil in the phantom itself may be disregarded, as in constructing the phantom coil, the windings in one side of the phantom circuit are wound upon different quadrants of the core from the windings in the other side of the phantom, and the capacity between the windings of the two sides of the phantom will be quite small, due to the physical separation of the windings. Therefore, the capacity introduced into the phantom by the phantom loading coil itself is not ordinarily considered in the design of the loading coil.

Since the capacity may be disregarded as above stated, it will be apparent that the principal effect of the carrier or side circuit loading coils in the phantom circuit is due to their resistance and leakage inductance. As the carrier or side circuit loading coils are usually of the air-core type (because of high frequencies employed in carrier transmission), the resistance and inductance effects are relatively larger than those which occur in ordinary loading, where the iron core type of loading coil is employed. The relatively large resistance of the air-core coils is a potential source of impedance irregularity at low speech frequencies, where the resistance of the conductor and the coils is an important factor in determining the characteristic impedance of the loaded cable. If the ratio of resistance to inductance per unit length in the loaded cable is different from the corresponding ratio of the associated open-wire line, there will be a difference in impedance which will cause irregularity at the low speech frequencies transmitted over the phantom circuit. This effect will of course also occur at the low frequencies transmitted over the speech frequency channels of the carrier circuits.

In order to prevent the impedance irregularities due to this difference in ratio from becoming objectionably large, it is desirable to design the carrier loading coils to definite resistance requirements, which depend upon the gauge of the cable conductor adopted as standard. No definite rule can be laid down, but in general the best practicable value of resistance is determined by a study in which cost considerations are balanced against transmission reactions. From the practical standpoint, the resistance requirements for the phantom loading units are established by the study which determines the resistance characteristics of the regular carrier coils, since ordinarily the latter coils occur six times as frequently as the phantom loading units.

Coming now to the inductance effects upon the phantom circuit of the carrier loading coils employed in the side circuit, it will be found that these inductance effects are greater than in the case of the iron-core coils which are used in the ordinary side circuit loading for ordinary voice frequencies. This is due in part to the employment of the air-core type of coil, and in part to the design of the winding of the coil. The air-core, being of very low permeability, produces comparatively large magnetic leakage, and this magnetic leakage produces a considerable inductance in the phantom, whereas, if the coil were perfect magnetically, the side circuit coil would produce no inductance in the phantom, owing to the balance of the windings. In designing the windings of the coil, it is necessary to employ a construction which will obtain a low mutual capacity. This necessitates the use of a relatively large amount of insulation between the inner and outer section windings of the coil, with the consequence that there is a greater separation between the windings. The increased separation, while reducing the mutual capacity, increases the leakage and results in a further increase in the inductance in the phantom, due to the side circuit coil.

In carrier loading coils of the type above described, the leakage inductance effect just considered amounts to nearly four per cent, whereas with the ordinary type of loading coil, the leakage which produces inductance in the phantom from the side circuit coils is much less than one per cent. This increased inductance effect in the phantom circuit may be readily cared for where the side circuits are loaded for carrier transmission, by considering the leakage inductance effects in the phantom as distributed inductance. This is entirely proper where the phantom is only used for the transmission of ordinary voice frequencies because of the much closer spacing of the carrier side circuit loading coil. In other words, the phantom loading effect of the side circuit coils is electrically equivalent to continuous loading and can be added directly to the distributed inductance of the phantom cable circuit in designing the phantom coil loading.

As a practical example, it may be stated that the effects of carrier loading coils in an existing commerical circuit employing the principles of the present invention supply approximately fifteen per cent. of the total inductance per unit length, which is necessary for satisfactory transmission over the cable phantom circuits. Therefore, the inductance of the phantom loading coils required on the phantom circuits of this installation, in which the side circuits are loaded for carrier operation, is approximately eighty-five per cent of the inductance of the coils, which would be required if the side circuits were loaded in the ordinary way for ordinary voice frequency transmission. The phantom loading effect of the carrier circuit loading coils thus makes necessary the use of different inductances in the phantom loading coils than are required in the ordinary voice loading of toll entrance cables connected with non-loaded lines.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at

intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit to be included in the phantomed group of conductors at the phantom loading points, said loading unit comprising a phantom loading coil and side circuit loading coils, the inductance of the side circuit loading coils being less than that of the side circuit loading coils at non-phantom loading points by an amount equal to the leakage inductance introduced into the side circuit at the phantom loading point by the phantom loading coil.

2. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit comprising a phantom loading coil and side circuit loading coils to be included in the phantomed group of conductors at a phantom loading point, said phantom loading coil introducing leakage inductance in the side circuit coils and the side circuit coils of the unit being designed to add sufficient inductance to the side circuits at the phantom loading point over and above the leakage inductance of the phantom to obtain a total coil inductance value in the side circuit at the phantom loading points equal to that supplied by the side circuit loading coils installed at non-phantom loading points.

3. A transmission system including a phantomed group of conductors, loading coils inserted in the side circuits of said group at certain intervals, loading coils included in the phantom circuit of said group at loading points coinciding with side circuit loading points and at intervals which are multiples of the side circuit loading intervals, the inductance of the side circuit loading coils inserted at phantom loading points being less than that of the side circuit coils at non-phantom loading points by an amount equal to the leakage inductance introduced into the side circuit by the phantom coil.

4. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit for use in said phantomed group at phantom loading points comprising a phantom loading coil and side circuit loading coils, the capacity of the side circuit coils of the loading unit being less than the capacity of side circuit coils used at non-phantom loading points by an amount equal to the capacity introduced into the side circuits by the phantom loading coil.

5. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit for use at phantom loading points of said phantomed group, said loading unit comprising a phantom coil and side circuit coils, said coils being so designed that the total mutual capacity introduced in the side circuits by the loading unit is approximately the same as the mutual capacity of the loading coils which are used at non-phantom loading points.

6. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit to be used at phantom loading points of said phantomed group, said loading unit comprising a phantom coil and side circuit coils, the windings of the phantom coils being so arranged that the capacity distribution of the phantom coil with reference to the side circuit will be substantially the same as the capacity distribution of the side circuit coil with respect to the side circuit.

7. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit to be included at phantom loading points in said phantomed group, said loading unit comprising a phantom coil and side circuit coils, the windings of the phantom coil being so arranged that the capacity between individual windings and the capacity between the windings and the pot will be distributed with reference to the side circuit in the same manner as the corresponding capacities of the side circuit coil are distributed.

8. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced

at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit for use at phantom loading points of the phantomed group, said loading unit comprising a phantom coil and side circuit coils, the phantom coil being made up of inner and outer windings upon each quadrant of a core and the side circuit coil including inner and outer windings upon each half of the core, each side circuit conductor passing through an inner winding on one quadrant of a phantom core and another winding upon another quardrant of a phantom core and also passing through an inner and outer winding upon different halves of the side circuit core, the winding connections of the phantom coil being such that the capacity between inner and outer windings and the capacity between the outer winding and the pot will be distributed with respect to the side circuit in the same manner as the corresponding capacities of the side circuit coils and one of the windings upon each quadrant of the phantom coil being wound in the opposite direction from the other winding.

9. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit for use at phantom loading points of a phantomed group, said loading unit comprising a phantom coil and side circuit coils, the windings of said side circuit coils being connected in the side circuit at the electrical center of the phantom coil line windings which are included in the side circuit conductors.

10. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit for use at phantom loading points of said phantomed group, said loading unit comprising a phantom coil and side circuit coils, the winding of the phantom coils being so arranged that the capacity of the coil with respect to the side circuit will be distributed in a manner similar to that of the capacity of the side circuit coil and the windings of the side circuit coils being connected in the side circuit at the electrical center of the phantom coil line windings included in the side circuit conductors.

11. In a transmission system comprising a phantomed group of conductors, the side circuits of which are loaded by coils spaced at intervals such as to give satisfactory transmission for a range of frequencies higher than that transmitted over the phantom and the phantom circuit of which is loaded by coils spaced at greater intervals than the side circuits, a loading unit for use at phantom loading points of said phantomed group, said phantom unit comprising phantom coils and side circuit coils, said coils being so designed as to obtain approximately the same total resistance in the side circuits at the phantom loading points as is introduced by side circuit coils included at non-phantom loading points.

In testimony whereof, we have signed our names to this specification this 29th day of June, 1922.

WLLIAM H. MARTIN.
THOMAS SHAW.