July 8, 1930. T. SHAW 1,769,969

NEUTRALIZING TRANSFORMER ARRANGEMENT

Filed July 10, 1929 2 Sheets-Sheet 1

Fig. 1

Schematic Arrangement — Neutralizing Transformer System

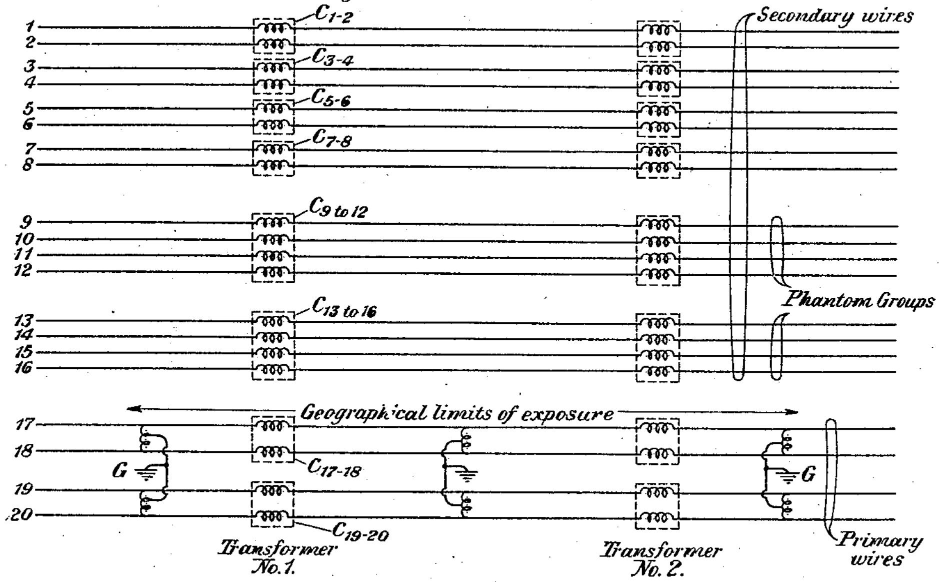

Fig. 2

Schematic Arrangement of Coils on Transformer Core

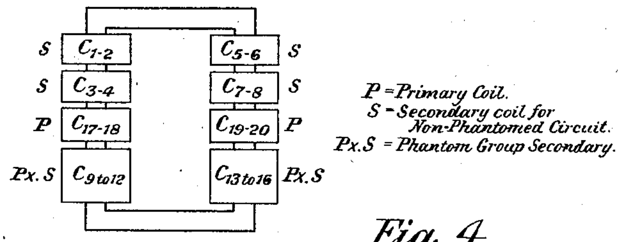

Fig. 3

Coil for Non-Phantomed Circuit
Schematic winding arrangement

○ = Wire
● = Mate

Fig. 4

Coil for Phantom Group
Schematic winding arrangement

○ = Quad cable which may be of Twisted Pair or Spiral Four construction.

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Fig. 5

On Non-Phantomed Open-Wire Circuits Arranged for Carrier Systems

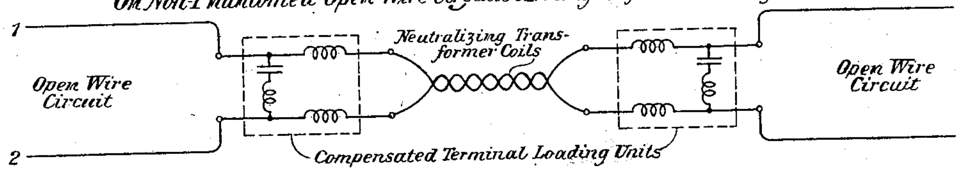
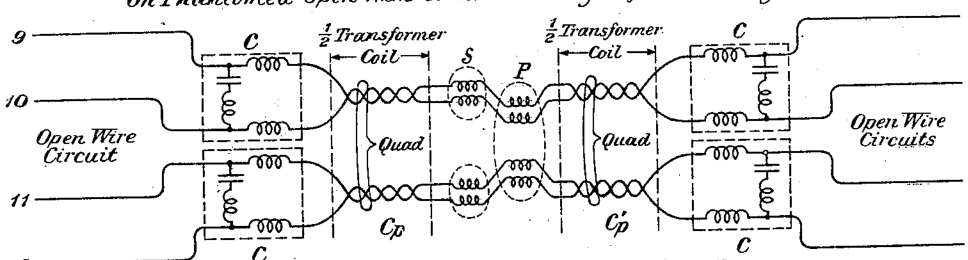


Fig. 6

On Phantomed Open-Wire Circuits Arranged for Carrier Systems

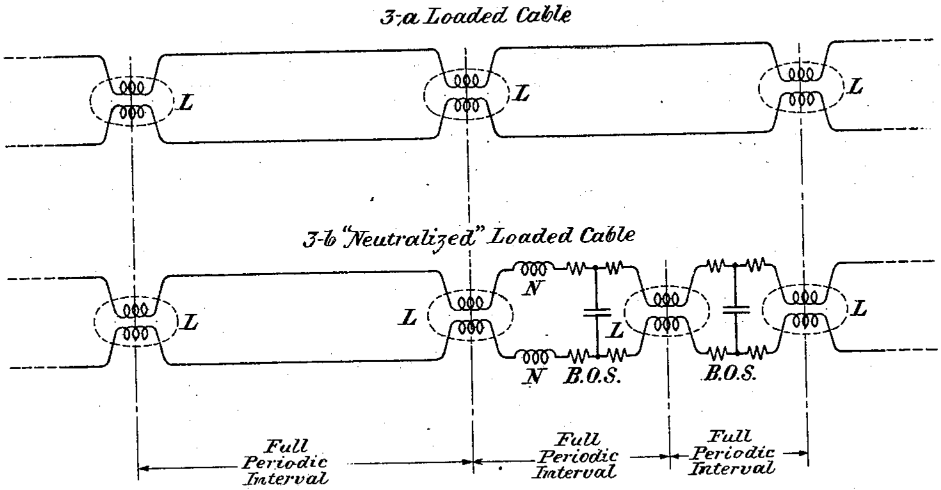


S = Full weight side circuit loading coil.
C = Compensated terminal loading units.
P = Phantom loading coil.

Fig. 7

Loaded Cable Circuits

3-a Loaded Cable



L = Loading coil.
N = Neutralizing transformer coil.
B.O.S = Building-out Section.

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UNITED STATES PATENT OFFICE

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NEUTRALIZING TRANSFORMER ARRANGEMENT

Application filed July 10, 1929. Serial No. 377,318.

This invention relates to transmission circuits, and more particularly to arrangements for reducing external interference upon such circuits.

Where telephone or other communication circuits parallel high voltage circuits such as power lines, the power lines introduce disturbing voltages on the telephone circuits. It has been proposed to reduce the disturbing voltages of the fundamental frequency by the use of neutralizing transformers. This involves providing an auxiliary circuit in which similar disturbances are induced and providing neutralizing transformers having primary windings in the auxiliary circuit and secondary windings in the disturbed telephone circuits, the secondary windings being so constructed and arranged that the voltages induced therein by the primary windings will tend to oppose those directly imposed by the power circuit.

Such neutralizing transformers were used in telephone circuits for neutralizing interference to a limited extent at a time prior to the growth of present day operating practices, which involve an extensive use of telephone repeaters on a two-way basis in the voice frequency circuits, and also the use of carrier systems on open wire lines. Under these essential practices, which are in common use throughout the telephone plant, only a small magnitude of impedance irregularities is permissible and neutralizing transformer systems heretofore proposed have involved impedance irregularities of such a character as to prevent their use in modern telephone systems.

In this connection it will be noted that neutralizing transformer coils have a considerable amount of mutual capacity and direct current resistance and certain of the designs that have been used in the past also add an appreciable amount of inductance to telephone circuits. In consequence, the neutralizing transformer coils cause an objectionable transmission loss in the telephone circuits in which they are used and also cause substantial impedance irregularities. These impedance irregularities would degrade the operation of the voice frequency telephone repeaters, due to impaired balance between the line and the balancing network circuits; they would impair transmission quality due to distortion caused by reflections, which effects would be particularly objectionable in the individual channels in carrier lines; moreover, they would greatly increase the carrier frequency crosstalk, due to reflection. These various impairments would tend to be particularly objectionable in multi-transformer installations, and in specific instances their cumulative effect would become intolerable.

In accordance with the present invention it is proposed to reduce the various telephone transmission impairments mentioned above by designing the individual transformer coils so as to have closely similar electrical characteristics to those of pieces of intermediate cables such as are frequently encountered in open wire lines, thus making it possible to use loading in connection with these transformers in accordance with practices now used in loading intermediate cables in open-wire lines. This concept imposes certain limits on the maximum mutual capacity permissible in a neutralizing transformer coil between conductors of the same telephone circuit and requires the direct current resistance to have a certain ideal ratio to the coil capacity, and furthermore, makes it desirable to have practically a zero leakage inductance in the associated telephone circuits. These general requirements can be approximated, so far as the design of the transformer is concerned, by using parallel winding arrangements for the transformer coil to reduce the leakage inductance to associated telephone circuits; by proper choice of conductor size so that the resistance will bear the right ratio to the coil capacity; and by suitably sectionalizing the transformer coils where the coil mutual capacity would otherwise be larger than the value which would fit in with the standard loading arrangement for the type of service involved. Where the transformer coil or the section of the coil has a capacity less than that of a standard loading section in an intermediate cable, the coil or coil section may be "built out" by means of an added capacity. In this connection it is to be noted that in open wire lines used for carrier systems the high frequency transmission requires the associated cable (or transformer) loading to have a high cut-off frequency which fact limits the mutual capacity allowed in a transformer coil to a much lower value than would be allowable when carrier frequencies are not involved.

The effect of properly loading the transformer coils would be to give to the coils substantially the same effective impedance as that of the lines with which they are associated, thereby reducing the impedance irregularity and the consequent reflection effects. The transmission losses in the transformer coils would also be reduced due to the general effect of the loading treatment, which raises the transformer impedance effective in the telephone circuits.

The invention will now be more fully understood from the following description when read in connection with the accompanying drawing in which Figure 1 is a schematic circuit diagram showing a typical arrangement of a neutralizing transformer system; Fig. 2 shows a typical arrangement of the transformer coils on the core; Figs. 3 and 4 show winding arrangements for the coils; Figs. 5 and 6 show how the transformer coils are built out and loaded in accordance with the invention; and Fig. 7 shows the application of the neutralizing transformer to a loaded cable circuit.

Neutralizing transformers—general description

The neutralizing transformer is a device for reducing the magnitude of longitudinal disturbing voltages of the fundamental frequency produced in telephone circuits by electromagnetic induction from parallel power distribution systems. It has a plurality of windings corresponding to the number of wires in the telephone line or cable which is exposed to electromagnetic induction, these windings being grouped in coils to take care of individual telephone circuits, the coils for non-phantomed circuits having two windings and those for phantom circuit groups having four windings. For example, referring to Fig. 1, six non-phantomed pairs having conductors numbered 1 to 8 and 17 to 20, inclusive, are shown, each wire including a winding for each neutralizing transformer of which latter two are shown. The windings of each pair, as, for example, 1 and 2, are associated together in the same coil as shown at C_{1-2}. Two phantom groups comprising wires 9 to 12 and 13 to 16 are also shown. Each wire of the phantom group includes a winding for each neutralizing transformer and the windings of the wires of a given phantom group, as, for example, 9 to 12, are included in the same coil as shown at C_{9-12}.

The windings of all coils are inserted in series with the telephone lines in such a way that a maximum impedance is presented to induced longitudinal currents, that is, the mutual inductances between the windings of a given coil aid the self inductances offered to induced longitudinal currents. Consequently the mutual inductances oppose the self inductances and minimize the impedance offered to the circulating telephone currents.

The transformer coils are divided into two groups of coils known, respectively, as "primary" and "secondary" coils, according to their functions in the neutralizing transformer system, as illustrated in Fig. 1. The primary coils, designteed C_{17-18} and C_{19-20} in Fig. 1, are inserted in the telephone wires that act as primary wires for neutralizing transformer system. In order to obtain optimum transformer action between the primary and secondary coils with respect to the induced longitudinal currents, it is desirable to distribute the primary coils evenly and symmetrically on the transformer core, with respect to the secondary coils. In the transformer design illustrated in Fig. 2, for use in a transformer system involving a total of four primary wires and sixteen secondary wires, two two-winding primary coils are required, one on each leg of the transformer core, at the approximate center.

The primary wires for the neutralizing transformer system, in which the primary coils are inserted, are grounded at each end of the section of open wire line or cable which is being neutralized by the transformer, as shown at G in Fig. 1. The induction currents flowing over the primary wires and through these primary transformer windings induce in the secondary transformer windings voltages which are in approximate phase opposition to the longitudinal voltages induced in the associated secondary wires by the disturbing power line. By proper design of the transformers and the neutralizing transformer system, the longitudinal voltages in the secondary wires can be reduced to be only a small fraction of the voltages which would act in the absence of the neutralizing transformers. Under these conditions, assuming approximately complete neutralization, no current of power fundamental frequency flows in the secondary windings and hence the neutralizing transformer works on practically a no-load basis. As is known, the effect of a load on the secondary of a transformer is to reduce the impedance looking into the primary. Since the neutralizing transformer is operating effectively on a no-load basis, the impedance of the primary windings to the longitudinal currents is therefore a maximum. This "choke coil" action of the primary transformer windings greatly reduces the magnitude of the longitudinal induction currents following in the primary telephone wires. By designing the transformers to make their primary impedance large with reference to the impedance of the primary line wires and grounds, the longitudinal voltages in the primary wires of the neutralizing transformer system can be reduced to the same order of magnitude as the unneutralized longitudinal voltages in the secondary wires.

The foregoing discussion is on the basis of using the primary wires of the neutralizing transformer system for telephone or other communication purposes. If the primary wires should have no other use than as primary wires for the neutralizing transformer system, the transformer primary coil construction may be simplified from that illustrated in Fig. 2. For instance, it would not be necessary to have more than one primary winding on each core leg and this would preferably be distributed evenly over the entire core leg. The secondary coils, each having two or four windings, depending as to whether non-phantomed or phantomed telephone circuits are involved, could be placed on the transformer core concentrically with the primary winding.

Impairment of telephone transmission performance

As a considerable number of telephone circuits are necessarily brought together in each neutralizing transformer, it is important to exercise great care in the design and manufacture of the transformers to avoid objectionable crosstalk between the different telephone circuits. This requires a balanced coupling among the windings of the telephone circuit coils. For example, consider conductor pairs 1—2 and 3—4. In order to avoid crosstalk, the windings of the coil C_{1-2} and C_{3-4} should be so related and mounted on the core that the mutual inductance from conductor 1 to conductor 3 will be the same as from conductor 1 to conductor 4. Also the mutual inductance from conductor 2 to conductor 3 should be the same as that from conductor 2 to conductor 4. These relations should also hold with respect to capacitative coupling between the windings of different telephone circuits.

In order to bring about a substantial degree of balanced coupling, so-called parallel winding arrangements have been used in the past for the transformer coils. The parallel wire winding arrangement for a non-phantom coil is shown in Fig. 3 and for a phantom group is shown in Fig. 4. Taking the non-phantom pair 1—2 of Fig. 1 for purposes of illustration, the two wires comprising the windings of the coil C_{1-2} are wound upon the coil form side by side as is shown in Fig. 3, and for each succeeding layer outwardly from the core of the two conductors, are reversed in position. This results in the individual parts of the two sets of wires comprising the coil being substantially uniformly distributed throughout the cross-sectional area of the coil with the result that the mutual inductance and the direct capacitance from an adjacent coil to any given conductor of coil C_{1-2}, for example, will be substantially the same as that to the other conductor of the coil.

In the case of a phantom group, the four wires comprising the phantom group, as, for example, wires 9, 10, 11, and 12, are twisted together either in the twisted pair formation used in quadded cable or in the well known spiral-four construction. The strand thus formed is then wound about the coil form as though it were a single wire with the result that the four individual wires of the quad are equally spaced through the cross-section of the coil. This also results in a good condition of magnetic balance.

While the parallel wire arrangement of the coils, as above described, is advantageous from the standpoint of balance so that the crosstalk is reduced to a minimum, the construction has an inherent disadvantage in that the coils have large mutual capacities between conductors of the same telephone circuit, due to their very close association with each other.

The large mutual capacity of the transformer coils, together with the resistance effects, cause transmission losses in the telephone circuits in which they are inserted, these losses being much greater for the high frequencies involved in carrier telephone transmission than in voice frequency transmission. By virtue of their large mutual capacity and associated series resistance of their windings, the transformer coils also act as impedance discontinuities in the otherwise uniform telephone circuit. Such impedance irregularities cause reflection effects which would (1) materially impair the operation of the telephone repeater in the voice-frequency channels of the carrier lines, and (2) cause transmission quality distortion, and (3) increase reflection crosstalk in the carrier channels. The magnitude of these transmission loss and reflection effects is a function of impedance of the transformer effective in the telephone circuit, this impedance being a function of the magnitudes of the mutual capacity, series resistance and series reactance of the transformer coils. In well designed and properly constructed coils, the effect of the leakage conductance in determining the coil loss and impedance characteristics is negligible. Now, in an open wire line with no transformer present, we have a uniform line with characteristic impedance dependent on distributed resistance, inductance, and capacity in accordance with the formula

$$Z=\sqrt{\frac{R+iL\omega}{G+iC\omega}}$$

where ω is 2π times the frequency of the telephone current and Z, R, L, G, and C are, respectively the impedance, resistance, inductance, leakage conductance and capacity. Here also the factor G is not of importance at the frequencies with which we are concerned, and with the type of line construction employed. In general, the ratio of the constants R, L and C of the neutralizing transformer coils will be materially different than the ratio of the corresponding series and shunt constants per unit length of the uniform line, so that an impedance irregularity would result.

The various transmission loss and reflection effects above mentioned would be objectionable for one transformer. If a considerable number of transformers should have to be used in order to obtain a satisfactory low value of unneutralized longitudinal voltage in the exposed telephone system, the net result of all of these transmission impairments could reasonably be expected in particular cases to make it impossible to operate carrier systems over the neutralized open-wire lines, or to give satisfactory service with telephone repeaters, in the voice frequency circuits.

Use of loading in conjunction with neutralizing transformers

An analysis of the various transmission difficulties mentioned above has resulted, in accordance with the present invention, in a new point of view in approaching the problem of improving telephone transmission conditions: namely, to design the neutralizing transformer coils so as to make them generally similar to length of intermediate cable introduced into open-wire lines as, for instance, when such lines pass through a town or across a river. If, then, the neutralizing transformer be loaded and terminated in accordance with the principles used in loading intermediate cable, it may be given improved transmission loss characteristics and the same impedance characteristics as the line in which it is connected.

As previously noted, the "parallel wire" construction of neutralizing transformer coils results in a considerable amount of mutual capacity and series resistance with a very low or practically zero series reactance. By proper care in the design and construction of the transformer coils, in accordance with the present invention the ratio of capacity to inductance to resistance may be made to approximate the corresponding ratio in the standard types of intermediate cables. Depending upon the degree of this approximation, the impedance characteristics and the transmission loss characteristics of the transformer coils can be improved by loading these coils in the same way that the impedance characteristics and transmission losses in intermediate cables in open-wire lines are improved by the use of standard types of intermediate cable loading.

A principal design requirement for such loading of intermediate cables is to alter the impedance of the cables so that there will be a negligible impedance discontinuity at the junctions of the cable and open-wire construction. In other words, the characteristic impedance of the loaded intermediate cable must be made equal to the characteristic impedance of the open-wire line over the entire frequency band involved in the use of the circuit. These standard loading methods require the introduction of lumped inductances at the ends of the intermediate cable (or at some intermediate point or points), so that the ratio of inductance to capacity per unit length in the intermediate cables will be effectively the same as the ratio of inductance to capacity per unit length in the open-wire line. These loading coils are spaced at the proper intervals, to obtain a sufficiently high cut-off frequency, so that the characteristic impedance of the loaded cable will be approximately the same as that of the open wire line throughout the entire frequency range normally involved in the use of the line. Also, in order to avoid impedance discontinuities at the low voice-frequencies where the conductor resistance is an important factor in determining the characteristic impedance of the circuit, it is desirable that the ratio of resistance to capacity per unit length in the loaded intermediate cables should be similar to the corresponding ratio in the associated open-wire lines. This requirement is ordinarily met to a satisfactory degree of approximation by choosing an optimum size of conductors in the cables. The existing standard loading systems and operating practices result in the fundamental impedance matching requirements being met to a satisfactorily close degree over the widest frequency ranges now involved in service over open-wire circuits.

In the preceding paragraphs special emphasis has been placed on the loading design to meet the ideal impedance matching requirements. An additional important advantage of such loading is that the transmission losses in the intermediate cables are also substantially reduced, approximately in the ratio of the impedance of the open-wire line to that of the (non-loaded) cable.

In explanation of this effect, it may be stated that in general the impedance of non-loaded intermediate cable is substantially lower than that of the associated open-wire line, primarily because of the much larger ratio of capacity to inductance, per unit circuit length. In low impedance lines, the principal cause of attenuation loss is heat dissipation due to the relatively large current flow in the series resistance of the circuit, this effect being proportional to the square of the current flowing and directly proportional to the magnitude of the resistance per unit length. The application of loading to such cables raises the circuit impedance thereby reducing the magnitude of the current flowing through the series resistance, and the magnitude of the heat losses which are proportional to the square of the series currents.

In accordance with the present invention, it is proposed to apply the foregoing principles used in connection with intermediate cable loading to the neutralizing transformer coil, using preferably a coil of the parallel wire-wound type previously described. In applying these loading principles to neutralizing transformer coils, however, the use of loading places certain definite limitations on the magnitude of the mutual capacity and the direct current resistance which would be permissible in a transformer coil in a given installation. These limits, of course, would depend on the frequency range involved in the use of the open-wire line and the characteristic impedance of the open-wire circuit as determined by the size of the wires and the pin spacing used in the open-wire line.

Use of carrier loading with neutralizing transformer coils

For example, it may be assumed that the neutralizing transformers are to be applied to a 165-mil open-wire non-pole pair circuit, with standard 12-inch pin spacing, and that the superposed carrier systems require frequencies as high as 30 kc. to be efficiently transmitted on the side circuits of the phantom groups and that the line impedance irregularities below this frequency are to be kept at a small value. The nominal impedance of the side circuits will then be about 600 ohms. The standard C-4.1 compensated loading would, under these conditions, be used to load side circuits of phantom groups in the entrance and intermediate cables in such open-wire lines. This loading uses full weight coils having 4.1 mh. inductance, spaced at intervals of about 930 feet and is applied to cables having a side circuit mutual capacity of 0.062 mf, per mile. This cable mutual capacity per loading section is about 10900 m-mf. The loaded system has a nominal cut-off frequency of about 45 kc. and a nominal impedance $\left(\sqrt{\frac{L}{C}}\right)$ of about 600 ohms.

In the use of standard C-4.1 loading in conjunction with neutralizing transformers on the type of line assumed in the preceding paragraph, the ideal value of mutual capacity for the transformer coils would be 10900 m-mf., that is, the standard cable loading section mutual capacity with which this loading was designed to work. In order to obtain the optimum impedance matching characteristic at the low speech frequencies where the conductor resistance is a factor in determining the characteristic impedance, each of the two line windings of a transformer coil such as C_{1-2} of Fig. 1 should have a direct current resistance of about 1.8 ohms. Under these conditions, the transformer coil would be substantially equivalent electrically to one 930-foot loading section in standard No. 13 American wire gauge cable, this being the optimum type of cable (as regards impedance characteristics) for use at intermediate points with 165-mil copper open-wire lines.

When standard C-4.1 loading is applied to cables in open-wire lines, there are placed at each end of the cable compensated terminal loading units consisting of a fractional weight loading coil having about 4.0 mh. inductance, shunted by an impedance compensator consisting of a 3120 m-mf. condenser in series with a 2.54 mh. inductance coil. This compensated loading termination has the property of adjusting the frequency impedance characteristic of the loaded cable to be similar to that of the associated open-wire line throughout the high frequency range involved in the use of the circuits. With ordinary half-coil or half-section loading terminations the impedance frequency characteristics of a loaded cable and a uniform line are substantially different at high frequencies even when the loaded cable and the open-wire line have the same nominal impedance $\left(\sqrt{\frac{L}{C}}\right)$. When there is only one loading section involved in an intermediate cable loading installation, compensated loading units are placed at each end of the cable. Fig. 5 illustrates this particular application of C-4.1 compensated loading to a two-wire neutralizing transformer coil having a mutual capacity of 10900 m-mf. and a resistance of 1.8 ohms per winding.

If the transformer coil should have a mutual capacity less than 10900 m-mf. it can be built out to the desired value by introducing into the circuit at one end of the coil a shunt condenser having an appropriate value of capacity. Also the resistance of the coil could obviously be "built out" by adding non-inductive resistances of proper magnitude in series with each transformer winding.

However, if design requirements set by neutralizing efficiency and cost considerations should result in the transformer coil mutual capacities being in excess of the ideal value given above (for the illustrative example under discussion), additional difficulty would be involved in applying the loading properly. One practical solution would be to sectionalize the coils, as schematically illustrated in Fig. 6 of the drawing. This involves the division of the transformer coils into a number of sections (two sectional divisions are illustrated in the drawing), each having a capacity of 10900 m-mf. or less. When the sections have a lower value of capacity than this, building out condensers can be used to adjust the capacity to this ideal value, as discussed above.

In such sectionalization of neutralizing transformer coils, it would be necessary to construct the coils so that there would be no electromagnetic or electrostatic coupling (with respect to telephone currents) between the coil sections; as otherwise the loading would not function properly according to design. This result may be accomplished by making separate coils of each half-section. For example, if a coil such as C_{1-2} in Fig. 2 is to be sectionalized, it would be made in the form of two separate coils each having two line windings.

By using well balanced parallel wire construction in the transformer coils, as illustrated in Figs. 3 and 4, each section of the transformer coil would be practically non-inductive to the associated telephone circuit, such, for example, as the pair 1—2 of Fig. 1, and there would consequently be practically zero magnetic coupling between the coil sections with respect to telephone circuits. (From the standpoint of longitudinal currents in these section windings, however, there would be a substantial electromagnetic coupling.) A simple way of eliminating electrostatic coupling between the transformer coil sections would be to shield each section from the others. For this purpose sheets of copper could be inserted between the coil sections. Such shields should be constructed to prevent the shield from acting as short-circuited turns on the transformer coil, and, as is well known, this result can be prevented by arranging the ends of the sheet of copper acting as a shield so that they overlap each other without contacting, this resulting in interrupting any possible conductive circuit through the copper while affording a shielding effect.

The foregoing loading discussion has been in terms of non-phantomed circuits, or side circuits of phantom groups, since these are the types of circuits used in high frequency carrier operation. In phantom group applications of neutralizing transformers, consideration would, of course, have to be given also to loading the phantom circuits of the four-wire transformer coils. At present, the phantom circuits of open-wire lines are used only for voice-frequency operation which fact considerably simplifies the loading requirements for the phantom circuits. The voice-frequency phantom loading associated with the C-4.1 carrier loading, uses 12.8 mh. (full weight) loading coils spaced at intervals corresponding to a phantom circuit mutual capacity of 106,000 m-mf. This is the capacity of 6 x 930 feet of standard cable having 0.062 mf. side circuit capacity per mile and 0.100 mf. phantom circuit per mile. The phantom circuit mutual capacity of any probable commercial design for neutralizing transformer phantom coils would be only a small fraction of this nominal value of phantom loading section capacity. With such designs, satisfactory loading can be provided for the phantom circuit by using a fractional weight loading coil at the middle of a two-section coil, as illustrated in Fig. 6. Here the neutralizing transformer is divided into two half-sections C_p and C_{p1}, and side circuit loading coils S are included in the side circuits between the sections, and the phantom loading coil P is included in the phantom between the sections.

The inductance of the loading coil in this arrangement would have to bear a certain ratio to the coil capacity, in order that the loaded transformer coil would have the same nominal impedance as the associated phantom open-wire circuit ($\sqrt{L_p/C_p}$). Compensating terminal loading units such as shown at C in Fig. 6 may be provided as already described in connection with Fig. 5. Obviously, instead of using one phantom loading coil at the center of the phantom transformer coil, as illustrated in Fig. 6, it will be permissible to use two loading coils at the terminals of the transformer coil, each coil having one-half of the inductance that would be the ideal value for a single loading coil used at the center of the transformer coils.

Voice-frequency loading for neutralizing transformer coils

The problem of loading neutralizing transformer coils occurring in open-wire lines used exclusively for voice-frequency transmission is less complex than the carrier loading problem above discussed, mainly because less severe electrical design requirements are imposed on the transformer coils. Although the available data on this point are limited, to a high degree of probability it is indicated that any design of transformer coil that would satisfy the voltage neutralization requirements would have a mutual capacity much less than that of a loading section in the standard voice-frequency loading for entrance and intermediate cables in non-loaded open-wire lines. On this basis, it would not be necessary to sectionalize the transformer coils and satisfactory impedance results could be obtained in all cases by using fractional weight coils at the terminals of the transformer coil circuits, with or without building-out arrangements. There is a possibility that the available fractional weight loading coils would not be the optimum coils for a particular transformer design. In such instances, it would not be difficult or unduly expensive to make available a suitable special loading coil. This operation might be less expensive than to use an available coil in those cases where a large amount of building-out capacity would be required in order to obtain satisfactory electrical results from the available coil. Problems of this kind are liable to be encountered occasionally in loading short intermediate cables in open-wire lines.

Transformer installations in loaded cable circuits

A somewhat different problem from those considered above would be involved if a neutralizing transformer should be installed in loaded cables operated in conjunction with telephone repeaters.

If the transformer should be installed at the time the cable is installed, the loading coil spacing could be arranged to allow for the capacity effects of the neutralizing transformer coils. For instance, if the transformer coil capacity should be equivalent to that of a quarter of a standard cable loading section capacity, the loading coils adjacent to the neutralizing transformer could be spaced 25 per cent closer than the normal spacing. If the mutual capacity of a complete transformer coil should be in excess of that of a standard cable loading section, it would, of course, be desirable to sectionalize the coils, as discussed in the open-wire line application considered above.

If neutralizing transformers should have to be installed on a cable that is already loaded, it would be necessary to add extra loading coils to the cable and to use capacity (and possibly also resistance) building-out arrangements in order to restore the regularity of the coil the spacing. Such an arrangement is illustrated in Fig. 7.

In the foregoing discussion, no distinction has been made between transformer primary coils and transformer secondary coils, with respect to telephone transmission impairments, or means for reducing the transmission impairments. This follows from the fact that the primary coils would be generally similar in design to the secondary coils in transformer installations where the primary wires of the neutralizing transformer system are used for telephone purposes.

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 system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a charactertistic impedance differing from that of the circuit in which it is included, and means to load at least one of said coils so that its impedance will be substantially that of the circuit in which it is inserted.

2. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a charactertistic impedance differing from that of the circuit in which it is included, and means to load at least one of said coils so that its attenuation will be decreased and its impedance will be substantially that of the circuit in which it is inserted.

3. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, means to build out at least one of said coils, and means to load any coil which is built out so that its impedance will be substantially the same as that of the circuit in which it is inserted.

4. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, means to build out at least one of said coils, and means to load any coil which is built out so that its attenuation will be decreased and its impedance will be substantially the same as that of the circuit in which it is inserted.

5. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, means to build out the capacity of at least one of said coils so that its ratio of capacity to resistance will be similar to that of the circuit in which it is inserted, and means to load any coil which is built out so that

its ratio of inductance to capacity to resistance will be similar to that of the circuit in which it is inserted.

6. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, means to build out the capacity of at least one of said coils so that its ratio of capacity to resistance will be similar to that of the circuit in which it is inserted, and means to load any coil which is built out so that its ratio of inductance to capacity to resistance will be such as to give it an impedance equivalent to that of the circuit in which it is inserted.

7. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, at least one of said coils also being divided into sections each having a capacity not exceeding that of a normal cable loading section, means to build out each section so that the ratio of capacity to resistance will be similar to that of the circuit in which the section is inserted, and means to load the section so that the ratio of capacity to resistance to inductance will be similar to that of the circuit in which they are inserted.

8. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, at least one of said coils also being divided into sections each having a capacity not exceeding that of a normal cable loading section, means to build out each section so that the ratio of capacity to resistance will be similar to that of the circuit in which it is inserted, and means to load the sections so that the ratio of capacity to resistance to inductance will be such as to produce an impedance equivalent to that of the circuit in which it is inserted.

9. In a system for neutralizing induced voltages, a transmission circuit subjected to induced voltages, an auxiliary circuit subjected to similar induced voltages, a neutralizing transformer comprising a primary coil in the auxiliary circuit and a secondary coil in the transmission circuit, said coils each having a characteristic impedance differing from that of the circuit in which it is included, and means to load at least one of said coils so that its impedance will be substantially that of the circuit in which it is inserted, and so that the cut-off frequency of the loaded transformer coil will be sufficiently high to permit efficient transmission of the highest frequencies involved in the use of the transmission circuit.

10. In a system for neutralizing induced voltages, a loaded transmission system exposed to induced voltage, a neutralizing transformer having a coil in the loaded transmission circuit, means for adjusting the impedance of the transformer coils by modifying its series resistance, shunt capacity and series inductance to have the same ratio of resistance to capacity to inductance and the same cut-off frequency as that of the loaded transmission system.

In testimony whereof, I have signed my name to this specification this 5th day of July 1929.

THOMAS SHAW.