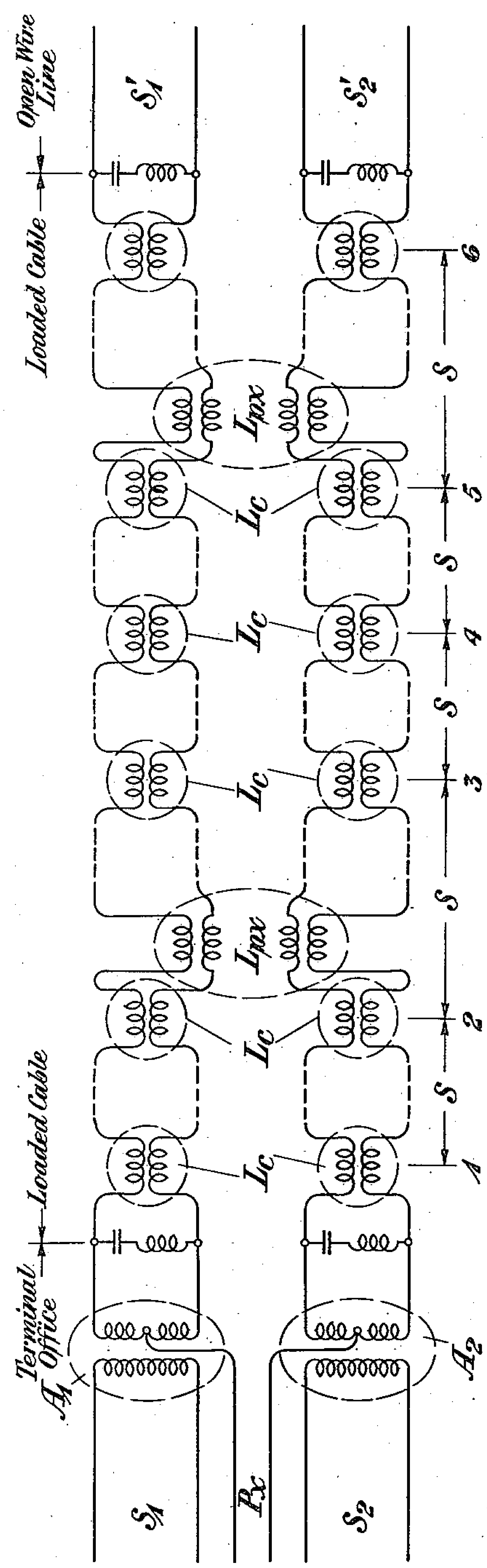
July 22, 1924. 1,501,926

T. SHAW

LOADED TRANSMISSION CIRCUIT

Filed June 30, 1922



INVENTOR.

T. Shaw

BY G. E. Folk

ATTORNEY

Patented July 22, 1924. **1,501,926**

UNITED STATES PATENT OFFICE.

THOMAS SHAW, OF HACKENSACK, NEW JERSEY, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK.

LOADED TRANSMISSION CIRCUIT.

Application filed June 30, 1922. Serial No. 571,849.

To all whom it may concern:

Be it known that I, THOMAS SHAW, residing at Hackensack, in the county of Bergen and State of New Jersey, 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 plan 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 telephone repeaters. These irregularities also cause reflexion 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 in accordance with the present invention 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 always expedient to use phantom circuits for carrier telephone and telegraph transmission systems because of cross-talk difficulties which would be encountered. Carrier systems are usually 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 frequency loading employed in connection with ordinary voice transmission.

The expedient of loading the phantom to the same cut-off frequency as the side circuits is not in general practicable because the number of loading coils per unit length increases with the cut-off frequency, and to load the phantom with the additional coils necessary to bring it up to the same cut-off frequency as the side circuits would be extremely expensive when it is considered that in the usual case no additional transmission channels would be obtained from the phantom by the extra loading because the phantom is unavailable for carrier transmission because of other limitations. It is therefore an important feature of the present invention to provide a system of loading, whereby the side circuits may be used for carrier transmission while the phantom circuit will be loaded only for ordinary voice transmission.

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 5600 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 in the phantom circuit should be allowed for in the phantom circuit loading design.

The manner in which these problems are solved may be understood from the following detailed description of the invention when read in connection with the accompanying drawing, the figure of which is a schematic layout of the loading of a section of cable intervening between a terminal office and a phantom group of open-wire lines.

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 line connections terminating at some point outside of the office. In the circuits S_1 and S_2, phantom terminating repeating 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 reactions 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 circuit 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 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 makes 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 point adds .10 milhenrys 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 distribution of these capacities, which affect the side circuit transmission, is fully discussed in U. S. Patent to Campbell and Shaw, Serial No. 980,921, of January 10, 1911, the capacity distribution being shown in the diagram of Fig. 3 of said patent.

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. These capacity effects of the phantom loading coil upon the side circuit may be allowed for 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 now the 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. This practice has also been followed in the loading of circuits for carrier purposes. In fact, owing to the short spacing of the carrier circuit loading coil and the irregular spacing of the cable manholes in which the loading coil pots are normally installed, it is more frequently necessary to install building-out condensers in carrier loading sections than in ordinary loading sections. Where it is necessary to supply building-out condensers in order to make the capacity of irregular carrier loading sections equal to the theoretical value of the loading design, it is not a severe hardship to allow also for the presence of capacity due to phantom loading coils as building-out condensers in the carrier circuit.

In new cable installations, however, involving carrier loading initially or ultimately, it is desirable and usually will be practicable to lay out the cable manholes 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 into 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 where carrier loading sections are approximately 900 feet long, the phantom coil irregularity effects " piles up " at frequencies which are approximate multiples of 11,000 cycles.

Under the conditions above specified, the effect of phantom coil capacity in the side circuit may be taken care of in either of 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 leading section.

Considering now the effects of the carrier circuit loading in the side circuit, upon the phantom loading, it will be seen that the capacity effects produced by the side circuit upon the phantom are very much less important than the capacity effects produced by the phantom loading upon the side circuit. This is because the normal capacity between the conductors of the phantom circuit independently of any capacity due to loading is very much larger than the corresponding capacity between the conductors of the side circuit, and consequently, any capacity effect produced by the loading of the side circuit is more or less masked by the comparatively large capacity of the phantom independently of loading. This is due to two reasons: First, the ordinary speech frequency phantom loading sections have approximately ten times as much mutual capacity as the ordinary carrier loading sections, this being in part due to the fact that an ordinary type of phantom circuit has a mutual capacity per unit length which is approximately sixty per cent 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 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 or of the loading.

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 inductances. 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.

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 magnetic 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 coils. 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 commercial 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. A transmission system including a phantomed group of conductors, the phantom circuit being loaded to transmit one limited range of frequencies and the side circuits being loaded to transmit another limited range of frequencies, one of said ranges being considerably wider than the other.

2. A transmission system including a phantomed group of conductors, the phantom circuit being loaded to transmit only a limited range of frequencies and the side circuits being loaded to transmit a wider range of frequencies.

3. A transmission system including a phantomed group of conductors, the phantom circuit being loaded to transmit only a range of frequencies corresponding to ordinary voice transmission and the side circuits being loaded to transmit carrier frequencies above the voice range.

4. A transmission system including a phantomed group of conductors, the phantom circuit being loaded with suitable coils spaced at proper intervals to give satisfactory transmission only within the voice range and the side circuits being loaded with coils designed for high frequency transmission and spaced at proper intervals to give satisfactory transmission for carrier currents above the voice range.

5. A transmission system including a phantomed group of conductors, the phantom circuit being loaded by coils spaced at certain substantially uniform intervals and the side circuits being loaded by coils spaced at quite different but substantially uniform intervals.

6. A transmission system including a phantomed group of conductors, the phantom circuit being loaded by coils spaced at certain substantially uniform intervals and the side circuits being loaded by coils spaced at more frequent but substantially uniform intervals.

7. A transmission system including a phantomed group of conductors, the side circuits being loaded by coils spaced at certain intervals and the phantom circuit being loaded by coils spaced at intervals corresponding to multiples of the side circuit intervals.

8. A transmission system including a phantomed group of conductors, the side circuits being loaded by coils spaced at certain intervals and the phantom circuit being loaded by coils spaced at intervals corresponding to multiples of the side circuit intervals, said intervals being so related that each phantom loading point will correspond to a side circuit loading point.

9. A transmission system including a phantomed group of conductors, the phantom circuit being loaded by coils designed and spaced at such intervals as to give satisfactory transmission over a range of frequencies, the side circuits being loaded with coils designed for high frequency transmission and spaced at such intervals as to give satisfactory transmission for a range of frequencies higher than that transmitted by the phantom circuit, the spacing of the coils being so chosen that the phantom loading points correspond to side circuit loading points, building-out condensers being included in the side circuits to build out those sections which are electrically shorter than the standard side circuit section and the capacity introduced into the side circuit by the phantom loading coil at phantom loading points constituting at least part of a building-out condenser for its section.

10. A transmission system including a phantomed group of conductors, loading coils in the side circuits spaced at certain intervals, loading coils inserted in the phantom circuit at points corresponding to side circuit loading points and at intervals constituting multiples of the side circuit intervals, building-out condensers included in the side circuit sections which are shorter than the standard loading section and the capacity of the phantom loading coil in the side circuit constituting at least a part of a building-out condenser for the corresponding side circuit section.

11. A transmission system including a phantomed group of conductors, loading coils in the side circuits spaced at certain intervals, loading coils inserted in the phantom circuit at points corresponding to side circuit loading points and at intervals constituting multiples of the side circuit intervals, the side circuit section including the phantom loading point being electrically shorter than the standard side circuit section and the capacity of the phantom loading coil in the side circuit constituting a condenser to build out the short section.

12. A transmission system including a phantomed group of conductors, loading coils included in the phantom circuit at

certain intervals and loading coils included in the side circuits at more frequent intervals, the loading coils in the phantom circuit being so designed as to increase the inductance of the phantom to transmit a desired range of frequencies, the leakage inductance of the carrier circuit coils upon the phantom increasing the distributed inductance of the phantom circuit, and the inductance of the loading coils for the phantom loading points being proportioned to compensate for such increase.

13. A transmission system including a phantomed group of conductors, loading coils included in the side circuits at intervals sufficiently frequent to enable the side circuits to transmit frequencies above the voice range, loading coils included in the phantom circuit at intervals constituting multiples of the side circuit intervals to enable the phantom to transmit voice frequencies, the inductance added by the phantom coils being proportioned to give the proper transmission characteristic upon the assumption that to the normal distributed inductance of the phantom the leakage inductance in the phantom due to the side circuit loading coils is added as additional uniformly distributed inductance.

14. A transmission system including a phantomed group of cable conductors connected to a corresponding phantom group of open-wire conductors, loading coils included in the phantom circuit at such intervals as to load the phantom for voice transmission and loading coils included in the side circuits at such intervals as to load the side circuits for the transmission of carrier frequencies above the voice range, the winding resistance of the side circuit coils and the phantom loading coils being so proportioned with respect to cable conductors of a given gauge as to give the loaded cable circuits approximately the same ratio of resistance to inductance per unit length as that obtaining in the open-wire line.

In testimony whereof, I have signed my name to this specification this 29th day of June, 1922.

THOMAS SHAW.