

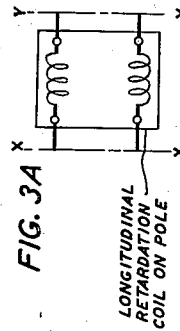
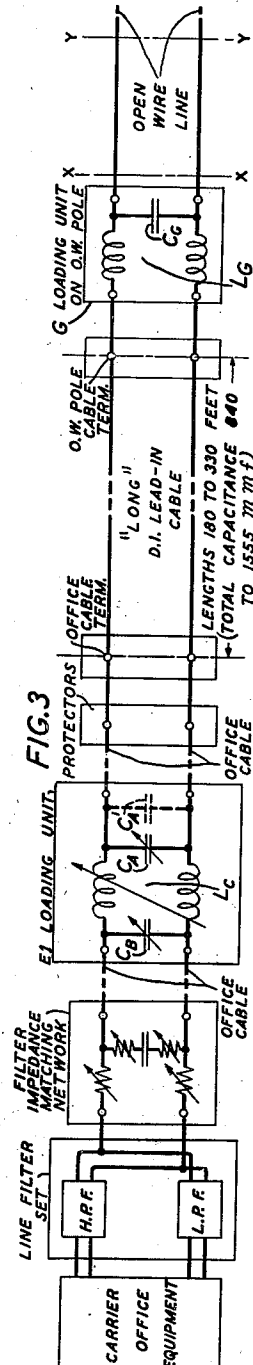
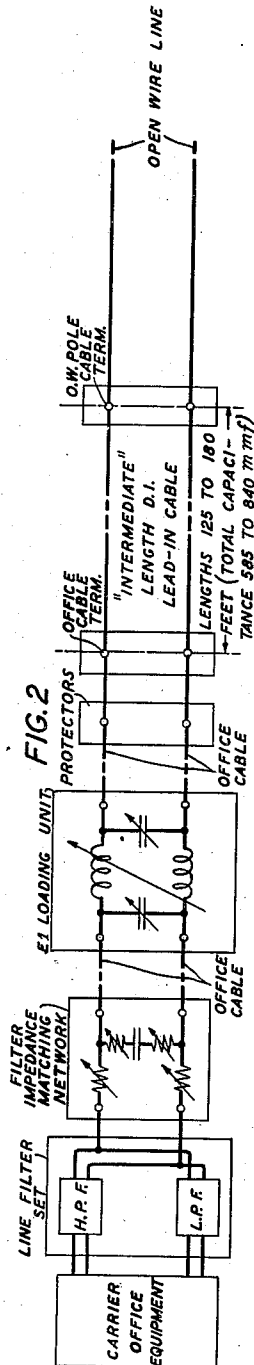
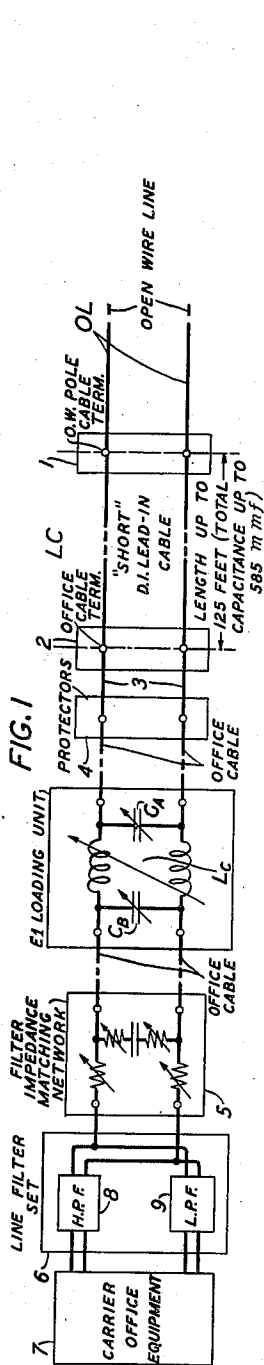
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LOADING SYSTEM

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LOADING SYSTEM

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The invention relates to loading systems and particularly to systems for loading short lengths of cable used in carrier wave signaling systems.

5 The invention is more specifically directed to the loading of short lengths of lead-in cable connecting the open-wire pairs in an open-wire carrier signaling system to office line filter sets at terminal and repeater points.

10 When such incidental cables are included in open-wire carrier signaling systems, such as a broad-band carrier telephone system, it is desirable to modify the impedance of the cable so that when it is terminated in office impedance, it will have as nearly as practicable the same character-
15 istic impedance as the open-wire line with which it is associated in the working signal frequency band. The purpose of this is to reduce to a tolerable amount impedance irregularities at the junction of the cable and the open-wire line, tending to produce reflection cross-talk in the
20 open-wire lines. The ideal way of accomplishing this is by loading the cable to open-wire impedance. However, economical and other practical considerations require different impedance
25 modifying treatments depending upon the length of lead-in cable involved.

Where long cables are involved, the cost of loading them to provide a close impedance match over a broad carrier frequency band may be prohibitively expensive, and in such instances the carrier line filter may be housed in a small building or hut located near the open-wire junction of the cable. The higher carrier frequencies are then passed through the filter to a nonloaded cable pair for transmission to the office. The lower carrier frequencies and voice frequencies are transmitted through another branch of the filter to another cable pair suitably loaded for transmitting these frequencies. Where the cable
40 extending from the carrier line filter set to the nearby open-wire terminal pole is comparatively short, the use of properly designed loading provides an economical method of modifying the cable impedance to provide an optimum terminal
45 impedance at the end of the bare open wire. Such short cables will be referred to in this specification as lead-in cables to distinguish from the longer cables generally required under toll entrance conditions and at intermediate points
50 between repeaters. In providing an optimum impedance termination for the open-wire pair, the loaded lead-in cable impedance should also match closely the impedance of the associated line filter set to minimize reflection effects at that
55 point in circuit, since, unless the filter set is

properly terminated on the open-wire side, the impedance which the filter set presents at its cable terminals may depart sufficiently from the ideal value to cause reflection cross-talk in the cable, in consequence of unavoidable small un-
5 balances in the cable. The lead-in cable loading problem is complicated by the technical necessity for having a loading cut-off frequency considerably higher than the highest frequency involved in the broad-band carrier systems transmitted
10 over the open-wire pairs, and by economic need for flexibility so that using relatively simple loading apparatus satisfactory impedance matches may be obtained with any type of open-wire pair
15 that may be used for the broad-band carrier systems, on any length of lead-in cable within a predetermined range of lengths. The open-wire impedances vary over a relatively wide range, because of differences in wire size and pin spacings. The length variations among the
20 lead-in cables are relatively much greater, due to variations in local conditions that determine the position of the filter hut relative to the open-wire terminal pole.

It is an object of the invention to improve the transmission and impedance characteristics of short lengths of cable connecting open-wire lines to office equipment at terminal and repeater points of a carrier signaling system.

Another object is to economically load short
30 lengths of cable employed in open-wire carrier signaling systems.

Another object is to provide loading for short lengths of lead-in cable connecting open-wire line pairs to carrier line filter sets at terminal
35 and repeater points in an open-wire carrier signaling system, which loading is adjustable to meet the transmission and impedance requirements for a considerable range of lengths and for a considerable range in open-wire impedances.

These objects are attained in accordance with the invention by using specially designed adjustable loading systems on the cables. These loading systems for maximum economy involve different fundamental apparatus arrangements, and
45 adjustments depending upon the cable length. In so-called "short" cables it has been found practicable to meet the impedance and transmission requirements by using an adjustable loading unit at one end of the cable, preferably located
50 at the filter hut for installation cost and convenience reasons. This adjustable loading unit comprises a series loading coil having a continuously variable inductance, connected in circuit
55 between two shunt variable capacitance elements.

To obtain equally satisfactory impedance matching results on the longest lead-in cables that are likely to be frequently encountered, it is necessary to use loading apparatus at both ends of the lead-in cable. For economy reasons, the loading unit used at the open-wire terminal pole consists of a simple combination of a fixed inductance loading coil, shunted on the open-wire side by a properly proportioned non-adjustable shunt condenser, different combinations of series inductance and shunt capacitance being required for association with open-wire lines having different impedances. In such so-called "long" lead-in cables, the adjustable loading unit designed primarily for the "short" cables is used at the filter hut end of the lead-in cable. Thus, irrespective of cable length, the same type of loading apparatus is used at the filter hut. The adjustments of this adjustable unit, however, are different for "long" cables than for "short" cables as will be subsequently explained. In a range of lead-in cable lengths intermediate between the so-called "short" and "long" cables, the loading apparatus is concentrated at the filter hut, and by special adjustments which are different in principle from those with "short" cable, a grade of transmission performance can be secured which is nearly as good as the best obtainable on the "short" cables, without incurring the increased costs that result from the use of loading apparatus at both ends of the cable. The range in variation of the adjustable elements in the adjustable loading unit used at the filter hut, and the nominal values of the fixed elements in the terminal pole loading units for "long" cables are selected to meet the range of impedance matching requirements that result from variations among open-wire pairs with respect to impedance and variations in length among the lead-in cables.

The various objects and features of the invention will be clear from the following detailed description thereof when read in conjunction with the accompanying drawing, Figs. 1 to 3 of which illustrate diagrammatically three different basic types of loading systems which embody the invention, and Fig. 3A shows schematically an additional transmission element which when used at the terminals of the open-wire line pairs of Figs. 1 to 3, requires a different adjustment of the loading arrangements therein.

The loading systems of the invention were developed for use with a special low capacitance lead-in cable which will be referred to as disc-insulated cable, because of the fact that the conductors of the pairs are held in position and insulated from one another by means of insulating discs. For economy reasons, the cable pairs are assembled in individual spiral-four quad units, each quad having magnetic and electric shielding applied in metallic tapes around the peripheries of the discs which space the four 16-gauge conductors of the quad. Diagonally opposite conductors of the spiral-four units are used as pairs for connection on a pair-to-pair basis with the open-wire pairs. A series of different cable lay-ups provide for different numbers of shielded quad units within a common sheath. The structural design of the quad units is such as to provide a design capacitance in the individual pairs of about 0.025 microfarad per mile, which is substantially constant with frequency over the broad frequency band involved in its use. The distributed inductance of the cable pairs is about 1.44 millihenries per mile at 150 kilo-

cycles, and about 1.8 millihenries per mile at low voice frequencies. Most of the inductance change with frequency occurs in the voice range. The conductance is very high and is a negligible factor in the design and the use of the loading.

The relatively high inductance of this type of insulated cable makes it necessary to use inductance adjustments as the components of cable building out when the cable lengths are shorter than the loading design assumptions, in meeting the precision impedance matching requirements that the difficult service requirements impose on the loading design. Loading arrangements conforming in design principle to the loading systems described herein could, of course, be worked out for use on other structural types of lead-in cable. Then, the values of the inductance and capacitance elements of the loading units would be somewhat different from those specified below, and for a given grade of transmission performance different geographical limits would be imposed on the arrangements using one loading unit and those using two loading units.

For the purpose of description, in the practical application of the invention lead-in cables may be classified with respect to length as "short," "intermediate length" and "long." The specific lengths of these cables will be given as applied to equivalent lengths of the disc-insulated cable described above based on capacitance as a criterion. Short lead-in cables will be defined as those which are shorter than the equivalent of about 125 feet of disc-insulated cable having a total capacitance of approximately 585 microfarads. Intermediate length lead-in cables will be defined as those which fall between the equivalent disc-insulated cable lengths of about 125 to about 180 feet, having a total capacitance between about 585 and 840 micro-microfarads. Long lead-in cables will be defined as those which fall between the equivalent disc-insulated cable lengths of about 180 to 330 feet, having a total capacitance between about 840 and 1555 micro-microfarads.

As shown in Fig. 1, short lead-in cables may be loaded in accordance with the invention by a single loading unit located at the filter end of the cable. Referring to Fig. 1, the terminals at one end of a pair or quad of the lead-in cable LC are connected through a sealed terminal 1 mounted on the cross-arm of the open-wire pole to the open-wire pair OL. The other end of the short lead-in cable LC is connected through an equivalent sealed terminal 2 and suitable wiring 3, which may be single 18-gauge silk-insulated and shielded wires bunched in a spiral-four group, to the protectors 4. Next in the circuit is the E/I adjustable loading unit which is connected by office cable, which may be a single pair of 22-gauge, shielded rubber-insulated wire, between the protectors 4 and the filter impedance matching network 5. Next in the circuit is the carrier line filter set 6 leading to the carrier equipment at the terminal or repeater office.

The line filter set 8 comprises a high-pass filter section 8 and a low-pass filter section 9 for separating the broad frequency band that is transmitted over the associated open-wire pairs into main subdivisions in conformity with service needs. The high-pass filter passes frequencies in the range 36 to 142 kilocycles, which are utilized by a new type of carrier telephone system for which the lead-in cable loading systems of the invention were devised, this system providing a maximum of twelve carrier telephone channels. The low-pass filter passes all frequencies below

about 31 kilocycles, this band of frequencies being used on the open-wire pairs for associated carrier telephone systems that provide three carrier telephone channels, for a voice frequency telephone channel, and for superposed direct current telegraph circuits below the voice frequency band. The precision impedance matching requirements that are imposed on the lead-in cable loading, as discussed below, are set by operating conditions in the frequency range used by the new twelve-channel carrier telephone system. When these high frequency requirements are met, the performance at the lower frequencies used by the three-channel telephone system and the voice channel should also be satisfactory. Thus from the standpoint of lead-in cable loading design, it is not a fundamental question whether the frequency division point in the line filter set 8 is provided by a suppression band in the region 31 to 36 kilocycles, as above described, or by a suppression band above the voice range and below the lowest frequency used in the three-channel telephone systems.

The precision impedance matching requirements for the lead-in cable loading are primarily necessary because of the very great practical difficulty of keeping the near-end cross-talk low in the design of open-wire lines and transpositions to control the very important far-end cross-talk. Since the carrier repeaters do not transmit near-end cross-talk as such, the line near-end cross-talk does not cause objectionable effects except when it is reflected at irregularities at the terminal or in the line, to become far-end cross-talk and cause objectionable increases in the total far-end cross-talk in the system. Studies of the lines used for the new high frequency carrier systems had indicated that the reflection coefficient at the junctions of open wire and cable should be kept within a limit of 5 per cent to avoid objectionable reflection cross-talk. This included allowances for irregularities caused by the loaded cable and by departures from ideal impedance characteristics in the line filter set and in the circuits and apparatus connected to the drop side of the line filter set.

To assist in meeting the reflection-coefficient limit at the end of the bare open wire, the line filter set has associated with it at the open-wire end an impedance matching network 5. The structural design impedance of the line filter set at the open-wire terminals when the drop sides of the high-pass filter and low-pass filter sections are ideally terminated, is about midway in the range of impedances of the different types of open pairs used for the new broad-band carrier telephone systems. Appropriate series elements of the network 5 are used to build up the filter impedance to match the higher impedance lines. When the filter is associated with lower impedance lines, appropriate shunt elements of network 5 modify the effective impedance downward to the desired degree. In some applications of lead-in cable loading discussed below, it is of advantage to modify the filter set impedance to a different value than that of the associated open wire by means of the auxiliary impedance matching network 5.

In designing the EI loading unit, a disc-insulated lead-in cable, as described above, of 125 foot-length was assumed to provide half-section termination on the open-wire side of the adjustable loading coil L_c , and the air condenser C_A was used to provide half-section loading termination at that point.

The EI loading unit for the lead-in cable comprises, as indicated, a series variable inductance L_c , which preferably is an adjustable air core loading coil of the variometer type, and two shut variable capacitances C_A and C_B , respectively located on the line and filter sides of the series inductance L_c , which are variable air condensers having very well balanced capacitances to ground for all values of shunt capacitance. The adjustable condenser C_A is used on the lead-in cable side of the loading coil, to build out the cable capacitance to the design half-section capacitance, when the cable is shorter than the design assumption. The variable inductance of the loading coil permits the selection of the correct inductance to provide optimum cable impedance for impedance matching purposes. Because of the half-section termination feature, this optimum loading impedance is a little below that of the open wire involved. The continuous inductance adjustability provided by the adjustable loading coil L_c is utilized to supply inductance "building-out" when cable length conditions make it necessary also to use capacitance building-out to conform to loading design assumptions. The primary function of the adjustable condenser C_B is to provide a desired fractional-section loading termination on the filter side of the loading coil, as required in the loading design.

The circuit arrangement and the types of apparatus units chosen for use in the EI loading unit were determined by basic considerations summarized in the following paragraphs. Inherent complications result from the fact that a range of lengths of cables must be loaded to have impedances closely matching the impedance of any one of a number of different types of line, differing in conductor size and spacing.

In the problem under consideration, the loading apparatus cannot be economically installed at an intermediate point in the lead-in cable. Very short cables can be satisfactorily loaded with a coil at one end, provided that the theoretical cut-off is high, relative to the highest working frequency. That is to say, at frequencies that are very low relative to the cut-off frequency, an inductance lumped at one end of a very short cable has the same effect as if the same amount of inductance were distributed uniformly along the cable, and there are no lumpy termination or directional asymmetry effects to consider. This simple type of loading would, however, be of little value in the present instance because of the severe restrictions imposed on cable length. Practical considerations thus lead to designs of loading systems which consist theoretically of a full weight loading coil working with half-section terminations on each side. The lead-in cable constitutes the whole of the half section on the open-wire side of the loading unit, being built out when necessary to conform to design assumptions, and a short piece of filter hut cabling which leads from the loading unit to the associated filter set is built out to approximate half-section termination on the filter side of the loading coil. A novel feature of the present invention is the use in a loading arrangement of this general type of a variable inductance loading coil to obtain any desired loaded cable impedance within a predetermined range, determined by the type of associated open-wire line, as well as a range of inductance building-out to take care of different lengths of cable within a given range, in conjunction with the

necessary cable capacitance building-out by associated variable condensers. Variable impedance loading systems for short fixed length lead-in cables could be provided with simple non-adjustable loading coils by using a variable building-out condenser to modify the cable impedance by increasing the effective lengths of the half-section terminations. If the cable should be shorter than the length assumed in the loading design, special types of building-out devices which provide series inductance in proper proportion to the shunt capacitance would be required for building out the cable. Studies of these methods of obtaining adjustable impedance loading systems showed the method illustrated in Fig. 1 to be preferable from the standpoint of performance characteristics for particular lengths of lead-in cable. For a given high standard of performance, considering all of the different weights of loading required, this method is suitable for longer lengths of cable.

The design procedure for the variable impedance loading and the continuously adjustable loading unit EI involves first the determination of the optimum nominal impedance of the loaded cable for the maximum and the minimum open-wire impedances involved in the use of the broad-band carrier telephone systems. The nominal impedance of the loaded cable is given by the expression

$$Z = \sqrt{\frac{(L+2l)}{2C}}$$

in which L is the inductance of the theoretical full coil of the loading design, C is the distributed capacitance of each of the theoretical half-sections, and l is the distributed inductance of each of the half-loading sections. Because of the half-section termination, the high frequency impedance is higher than the nominal impedance by an amount that depends upon the cut-off frequency of the loading. Since, in general, it is more important to have a good impedance match at the upper transmitted frequencies than at the middle and low frequencies of the carrier band, it is desirable that the nominal impedance of the loading shall be somewhat lower than the high frequency impedance of the associated open wire. The optimum ratio of cable nominal impedance to open-wire impedance is determined by computation. In the highest impedance loading required for 125-foot lengths of lead-in cable, the optimum ratio of nominal cable impedance to open-wire impedance is approximately 0.97 and the theoretical cut-off frequency is about 480 kilocycles. Under these assumptions, the theoretical full-coil inductance is approximately 348 microhenries. Since the adjustable loading coil must provide inductance building-out adjustments for the lead-in cable, when it is much shorter than the transmission design limit, the effective inductance must be larger than the theoretical full-coil value above mentioned. Furthermore, the half-section termination on the filter side of the loading coil will consist principally of a building-out condenser to supplement the short piece of office cable, the adjustable loading coil must also provide a proper amount of inductance for association with the filter side condenser to simulate half-section terminations on this side of the loading coil. Theoretical computations have shown that it would not be necessary to have a separate inductance located on the filter side of the condenser.

The design study briefly summarized showed

that it would be desirable for the highest impedance loading to have a total inductance of about 420 microhenries in the continuously adjustable loading coil component of the EI adjustable loading unit, and that it would be desirable to have a maximum capacitance of about 440 micro-microfarads in the building-out condenser CA on the open-wire side of the loading coil. This latter figure is on the assumption that the shortest lead-in cable would be approximately 40 feet long. The variable condenser CB on the filter side of the loading coil LC requires a maximum value of about 625 micro-microfarads. It is not practicable nor necessary to have a minimum value of 0 micro-microfarad in the adjustable condensers. In condenser CA, the minimum value is of the order of 12 to 15 micro-microfarads, while in the condenser CB, the corresponding minimum is about 20 to 25 micro-microfarads.

In continually adjustable inductance coils of the variometer type used in the present invention, it is not practicable to work to very high ratios of maximum to minimum inductance. For this reason, in order to determine design requirements for the adjustable loading coil, it was necessary to determine the theoretical optimum loaded cable impedance to match the lowest impedance type of open-wire line that is involved in the use of the new broad-band carrier systems, this impedance being of the order of 510 ohms. Since for fixed lengths of cable, a low impedance loading provides a higher cut-off frequency than that in higher impedance loading, the optimum ratio of loaded cable nominal impedance to open-wire impedance is somewhat higher than that for the 610-ohm loading above mentioned. For the 510-ohm impedance loading, it is important that the minimum inductance of the adjustable loading coil should not be higher than the optimum value required when no inductance building-out is required in the lead-in cable. This minimum inductance adjustment of course must include an allowance for the inductance required in the inductance-condenser network that simulates the half section of cable required on the filter side of the theoretical full-weight loading coil. These considerations set the minimum inductance value of the loading coil at about 250 microhenries. The ratio of maximum to minimum inductance required in the range of loading impedances involved thus works out to be approximately 1.8 to 1, which was found to be entirely practicable from the standpoint of physical design.

In the EI loading units which were constructed, calibrated dials were used on the axes of the shafts which support the adjustable loading coil and the adjustable condensers to permit settings of the inductance and capacitance values of these elements to any value that is necessary to get optimum impedance loading within the range of open-wire impedances involved and for any length of lead-in cable between approximately 40 and 125 feet. Theoretical computations on field measurements show that when the loaded cable is working under ideal impedance terminations assumed in design, reflection coefficients as low as 1 per cent may be obtained at the cable open-wire junction.

Having been designed primarily to provide half-section terminations on each side of full coil, with a 40 to 125-foot lead-in cable functioning (with appropriate capacitance and inductance building-out, when necessary) as the open-

wire side half-loading section, the variable inductance loading unit above described does not have a sufficient range of inductance and capacitance to meet the loading requirement for cables materially in excess of 125 feet. It was found from theoretical studies and confirmed by experiment that by accepting a moderate increase in reflection coefficient at the end of the bare open wire, the adjustable loading units could be used for longer lengths of cable up to about 180 feet. This range of cable lengths is designated as "intermediate" lengths, and requires a different fractional termination on the filter side of the adjustable loading coil from that used on the open-wire side, for which reason these extension loading arrangements may be designated "asymmetrical" loading. The schematic circuit for loading intermediate length cables is given in Fig. 2. It is generally similar to Fig. 1, except for length of cable and for difference in the absolute values of apparatus adjustments.

The transmission theory involved in the choice of the fractional-section termination on the filter side of the adjustable inductance loading coil is based on U. S. Patent 1,733,127 issued to Benjamin F. Lewis on October 29, 1929 (refer to Fig. 11), with modifications in application that result from the fact that the cable here involved has an unusual high ratio of distributed inductance to capacitance. It has been found that within the scope of the available apparatus, the optimum end section on the filter side of the loading coil is 0.37 section and that the inductance provided by the adjustable coil should be sufficient, in conjunction with inductance of the built-out cable sections to provide approximately .815 of "full section" inductance. This "full section" inductance is the theoretical total inductance that would be provided by two half sections of disc-insulated cable, each 180 feet long and the theoretical full coil to obtain the optimum nominal loaded cable impedance for impedance matching at the high carrier frequencies. Depending on the loading cut-off, this nominal value of cable impedance is several per cent below the high frequency normal impedance of the associated open-wire line, ranging from about 95 per cent with 610-ohm open wire to about 98 per cent for 510-ohm open wire. With asymmetrical loading, the ratios of cable nominal impedance to open-wire impedance are somewhat lower than with the asymmetrical half section terminated loading of Fig. 1, due primarily to the lower cut-off frequency that results from the increased length of half sections. The frequency impedance characteristic provided by the 0.37 section termination on the filter side of the 0.815 "fractional" coil is much flatter over the upper carrier frequency band than that provided by half-section termination working in conjunction with a "full" coil. For this reason, the filter impedance correcting network 5 is adjusted downward to provide a filter terminal impedance equal to the nominal impedance of the loaded cable, which, as previously noted, is several per cent below that of the associated open-wire line.

For disc-insulated cables in excess of about 180 feet, it is necessary to use loading apparatus at each end of the cable in order to secure precision impedance matches with the different types of open-wire lines involved. For flexibility in engineering it is desirable to use at the filter end of the long lead-in cable, as shown in Fig. 3, the E1 adjustable loading unit that was designed especially for use on short cables. This loading unit, so far as electrical features are concerned,

could also be used at the open-wire end of the cable but, in general, this procedure would be unduly expensive. For example, since the two loading units work at opposite ends of the same loading section, as shown in Fig. 3, it is not necessary that both units be designed to permit inductance and capacitance building-out adjustments. These and other economic considerations make it desirable to use a simple design of non-adjustable loading unit at the open-wire end of the lead-in cable.

In the loading treatment for long lead-in cables illustrated in Fig. 3, the basic transmission theory is that the lead-in cable (built out when necessary to conform to design assumptions) constitutes a "full" loading section having "fractional-section" loading terminations at each end. Theoretically this termination is similar to that used on the filter side of the loading coil in the treatment above described for intermediate length cables. The detail transmission design is based on a 330-foot length of disc-insulated cable pair, for two specific reasons; (1) very few, if any, lead-in cables will be of greater length, and (2) the adjustable loading unit E1 designed to be used alone with short and intermediate cables, has a sufficient range in adjustability to provide the desired type of loading termination at the filter end of a cable not materially in excess of this length. By using the transmission theory disclosed in U. S. Patent 1,475,997 to Ray S. Hoyt, issued December 4, 1923, disc-insulated lead-in cables up to about 640 feet could be satisfactorily loaded by means of special designs of loading units located at each end. Such units would include special susceptance neutralizing networks, and because of the complication of their circuits, it would be unduly expensive to provide adjustability for impedance matching with different types of open-wire lines. Different designs of loading units would thus be required for different line impedances. Such loading units would not conform to engineering flexibility requirements in the filter hut layouts. They would be suitable, however, for loading multisection entrance and intermediate cables of the disc-insulated structure.

The loading arrangements of Fig. 3 are intended for "long" lead-in cables, in the range 180 to 330 feet. They are loaded, as indicated, by a G non-adjustable loading unit at the open-wire end of the cable, which provides the desired fractional-section termination at that end of the cable, consisting of a shunt mica condenser C_G and a fractional weight loading coil L_G , the loading unit being designed for high frequency working in carrier systems. These apparatus elements are unadjustable. Typical designs of G units which are used on cables associated with 575-ohm and 542-ohm open-wire lines, use condensers having a capacitance of about 490 micro-microfarads, and loading coils having 376 and 327 microhenries, respectively. The E1 loading unit in the filter hut used at the other end of the cable, is adjusted to provide an electrically similar loading termination. The adjustment of condenser C_B in the latter unit takes into account the capacitance of the filter hut cable, leading from the E1 loading unit to the line filter set 6. The series loading coil L_C is adjusted to provide the theoretical value of the optimum fractional weight loading coil required in the loading termination, similar to L_G in the G loading unit, and in addition provides whatever cable inductance building-out which may be required when

the lead-in cable is less than the design limiting length of 330 feet.

For certain lengths of long lead-in cables, the required amount of capacitance building-out may exceed the value which can be supplied by the line side building-out condenser C_A used in the EI loading unit, and it is desirable in those cases to connect an auxiliary, non-adjustable, building-out condenser C_A' of suitable value in parallel with the adjustable condenser C_A to extend the adjustment range of the EI loading unit, as indicated by the dotted lines in Fig. 3. The addition of such a non-adjustable condenser would be required principally for the building-out adjustments of long lead-in cables in the range of equivalent disc-insulated cable lengths 175 to 240 feet. Computations have indicated that the size of this non-adjustable condenser would be in the neighborhood of 400 micro-microfarads.

The fact that electrically similar, partially compensated, loading terminations are used at each end of the long lead-in cables, as shown in Fig. 3, and the further fact that for the length of cable involved the loading cut-off is high relative to the top working frequency, makes it practicable to design the loading to have a nominal impedance closely equal to the theoretical open-wire impedance assumed in the loading design, and also makes it desirable to adjust the line filter set to have an impedance close to that of the open wire.

By computations in accordance with the design theories outlined above, it is practical to set up relatively simple rules for the adjustment of the apparatus elements of the EI loading unit, and the selection of the proper type of G loading unit (when required) for the various lengths of lead-in cables that may be required between open-wire terminal poles and the line filter sets in nearby filter huts, to secure high grade matching of the cable impedance with any type of open-wire line on which the new broad-band carrier telephone systems can satisfactorily be used. In such theoretical rules, unless measurements of the actual impedance of the associated open-wire line and the line filter set are made, it is necessary to assume that these impedances are in accordance with design theory. Because of unavoidable small departures from theoretical spacing of the wires and differences in sags and in transposition of systems, different open-wire pairs of the same type will have somewhat different impedance values. For this and other reasons mentioned below it is advantageous to make the loading apparatus adjustments in terms of return losses, measured at the junction of the open-wire and lead-in cable. In such measurements the apparatus elements of the EI loading unit are adjusted on a systematic basis until the maximum return loss is obtained in the upper part of the transmitted frequency band. In such adjustments, the small negative reactance of the line filter sets may be allowed for in the adjustments of condenser C_B of the EI loading unit, and the auxiliary filter impedance matching network 5 may also be adjusted to the optimum value. Furthermore, the adjustments of condenser C_A and the coil L_C can be made to offset, to a greater or less degree, the effects of impedance irregularities caused by longitudinal retardation coils shown in Fig. 3A, when these coils are installed at the end of the bare open wire to suppress longitudinal currents that might otherwise cause interaction cross-talk difficulties. These coils add a very large series impedance

to the longitudinal circuit, and a small, but not negligible, series impedance and shunt impedance to the metallic circuit. These latter effects vary from coil to coil.

Experimental tests of loading systems such as illustrated in the drawing and described above have shown that the range of capacitance and inductance variations obtainable in the adjustable loading unit as described above will provide desirable transmission and impedance characteristics for substantially all lengths of lead-in cable required in a commercial open-wire carrier telephone system.

Although the loading arrangements of the invention have been specifically designed for use with a particular type of lead-in cable of specified low capacitance, it is apparent that by using different values for the capacitance and inductance elements of the loading units they may be applied equally well to other types of cable of lengths and total capacitances different than those specified. It is to be understood that the particular values for the values of the capacitance and inductance elements in the loading unit and the range of variations in these values are given by way of example only and are not to be taken as limitations of the scope of the invention. Various modifications of the loading systems as described above which are within the spirit and scope of the invention will occur to persons skilled in the art.

What is claimed is:

1. A variable impedance loading system for lead-in cables connecting open-wire line pairs to carrier office apparatus at a terminal or repeater station of a wide frequency band carrier signaling system, said lead-in cables being of varying length and total capacitance within a first predetermined range and said open-wire line pairs having impedances within another predetermined range, comprising a loading unit at the carrier office end of the cable, including an adjustable loading coil having a range of inductance variation such as to enable its adjustment to raise the impedance of any lead-in cable within said first predetermined range to a value that closely matches the impedance of any connected open-wire line pair of impedance within said other predetermined range over the working frequency band.

2. A variable impedance loading system for lead-in cables connecting open-wire line pairs of a wide frequency band carrier signaling system to office line filter sets at terminal or repeater stations of the system, said lead-in cables being of varying length and total capacitance within a first predetermined range and said open-wire line pairs having impedances within another predetermined range, comprising a loading unit at the office end of the cable, consisting of a series adjustable loading coil having a range of inductance variation such as to enable its adjustment to match the impedance of any lead-in cable within said first predetermined range to that of any open-wire line pair having an impedance within said other predetermined range over said wide frequency band and to provide the necessary cable inductance building-out, and associated adjustable condensers having a range of capacitance variation such as to provide the necessary cable capacitance building-out.

3. A variable impedance loading system for lead-in cables connecting any one of several different types of open-wire pairs to carrier office apparatus at terminal or repeater stations of a

broad frequency band carrier signaling system, said lead-in cables being of varying length and capacitance within a first predetermined range and said open-wire pairs having impedances within another predetermined range, comprising a loading unit at the carrier office end of the cable, having variable inductance and variable capacitance elements with a range of inductance and capacitance variation, respectively, such as to enable adjustment of the loading unit so that over the entire frequency band transmitted by the open-wire pairs the transmission loss in any length of the loaded cable within said first predetermined range will be low and its impedance will closely match the impedance of any open-wire pair within said other predetermined range and the impedance of the associated carrier office apparatus.

4. A variable impedance loading system for lead-in cables connecting open-wire line pairs to an office carrier line filter set at terminal and repeater points of a broad-band, open-wire carrier frequency signaling system, said lead-in cables being of varying length and total capacitance within a first predetermined range, comprising a loading unit at the filter end of the lead-in cable, consisting of a series variable inductance element connected between two shunt variable capacitance elements, having a range of inductance and capacitance variation, respectively, such as to enable adjustment of said loading unit so that over the entire frequency band transmitted by the open-wire pairs the transmission loss in any length of the loaded cable within said first predetermined range will be low and its impedance will closely match the impedance of any open-wire pair of an impedance within another predetermined range.

5. The system of claim 3 in which the variable inductance and capacitance elements in said loading unit comprise a series variable inductance loading coil and two shunt variable capacitance condensers respectively located on either side of said loading coil, the capacitance of the line side condenser being adjustable in relation to the capacitance of the lead-in cable to provide a half loading section on the line side of the loading coil, the capacitance of the filter side condenser being adjustable in relation to the capacitance of the connection between said loading unit and said line filter set to provide a half loading section on the filter side of said loading coil, and said loading coil being adjustable to provide optimum inductance building-out for each of the half loading sections to enable them to conform to loading design assumptions on total cable inductance, and in addition to provide the necessary value of full coil inductance which, acting in conjunction with the capacitance-inductance built-out half sections, provides the optimum value of lead-in cable impedance for matching the impedances of the associated open-wire pair and line filter set.

6. The loading system of claim 3 in which the variable inductance and variable capacitance elements in said loading unit comprise a series variable inductance loading coil and two shunt variable capacitance condensers respectively located on the line and filter sides of said loading coil, the capacitance of the filter side condenser being adjustable in relation to the capacitance of the connection between said loading unit and said line filter set to provide approximately a 0.37 loading section on the filter side of said loading coil, and said loading coil being adjustable to

provide optimum inductance building-out for each of the fractional length loading sections to enable them to conform to design assumptions on total lead-in cable inductance, and in addition to provide the particular value of fractional coil inductance, approximately 0.815 of full coil inductance, which is optimum for working into half section cable and 0.37 section cable on the filter side, in order to obtain the optimum cable impedance for matching the impedance of the associated open-wire pair and that of the line filter set having its impedance adjusted to work with that open-wire pair.

7. A system for loading lead-in cables connecting open-wire carrier line pairs to office carrier line filter sets in a wide-band carrier wave signaling system, said lead-in cables being of varying length and total capacitance within a predetermined range, comprising a loading unit connected at each end of the lead-in cable, the loading unit at the filter end of said cable comprising variable inductance and capacitance elements and the loading unit at the open-wire line end of said cable comprising fixed inductance and capacitance elements, the inductance and capacitance of the elements of the two loading units being adjusted or selected to provide similar compensated fractional section loading terminations at each end of the cable and to provide close impedance matching at the junction of the lead-in cable and the connected open-wire line pairs, and at the juncture of the lead-in cable and the filter set, irrespective of the length and total capacitance of the cable if within said predetermined range.

8. The system of claim 3, in which said lead-in cables have a design capacitance of approximately .025 microfarad per mile and distributed inductance of about 1.44 millihenries per mile in the carrier frequency band, and are within a range of lengths up to about 180 feet having a total capacitance up to about 840 micro-microfarads, the variable inductance element of said loading unit provides a range of inductance variation between 250 and 450 microhenries, the line side variable capacitance element of said unit provides a capacitance variation ranging from a minimum value of the order of 12 to 15 micro-microfarads to a maximum value of about 440 micro-microfarads, and the filter side variable capacitance element provides a capacitance variation ranging from a minimum value of about 20 to 25 micro-microfarads to a maximum value of about 625 micro-microfarads.

9. The system of claim 3 in which said lead-in cables have a design capacitance of about .025 microfarad per mile and about 1.44 millihenry inductance per mile in the carrier frequency range and range from about 125 to 180 feet in length and from about 585 to 840 micro-microfarads in total capacitance for each cable, said variable inductance element of said loading unit is adjusted to provide a total inductance for the loaded cable which is about 0.815 of full section inductance, and said variable capacitance elements are adjusted asymmetrically so as to provide such capacitance that the loaded lead-in cable is approximately terminated in mid-section at the open-wire end and at about 0.37 section at the filter end.

10. A system for loading lead-in cables connecting open-wire line pairs to a line filter set at a station of a broad-band carrier frequency signaling system, said lead-in cables being of varying length and total capacitance within a

first predetermined range, in which the lead-in cable constitutes a full loading section having at the open-wire end a non-adjustable loading unit providing a compensated loading termination, consisting of a series fractional weight loading coil approximately 0.815 full coil and a shunt condenser on the open-wire side of said coil, having a capacitance equivalent to 0.37 full section, and at the filter end of said cable an adjustable loading unit comprising a series variable inductance element working between two shunt variable capacitance elements, said adjustable loading unit being adjustable to provide the necessary inductance and capacitance building-out to enable the total inductance and capacitance of the lead-in cable to conform to require-

ments for a full loading section and to provide a total capacitance on the filter side of the series variable inductance element, and the optimum value of fractional coil inductance for securing a compensated loading termination at the filter end of the cable electrically equivalent to that provided by the non-adjustable loading unit at the open-wire end of the cable, the values of full section cable and full coil inductance being optimum from the impedance matching standpoint for use with any carrier open-wire pair of impedance within a predetermined range and a line filter set having its impedance adjusted to work with that open-wire pair.

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