

June 27, 1939.

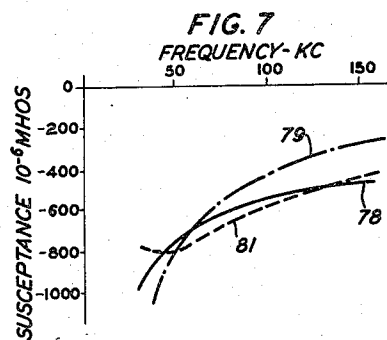
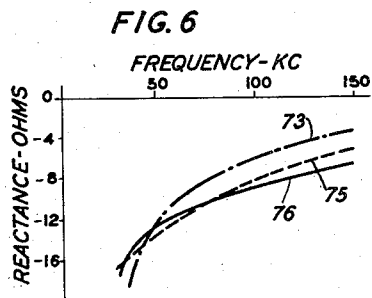
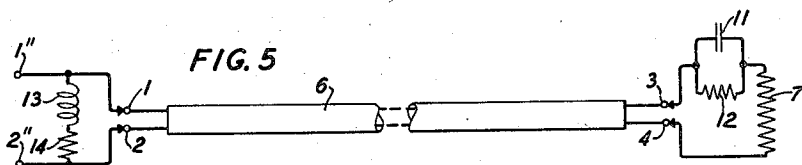
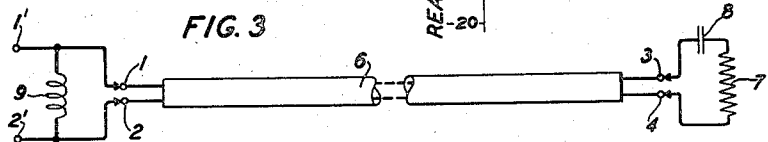
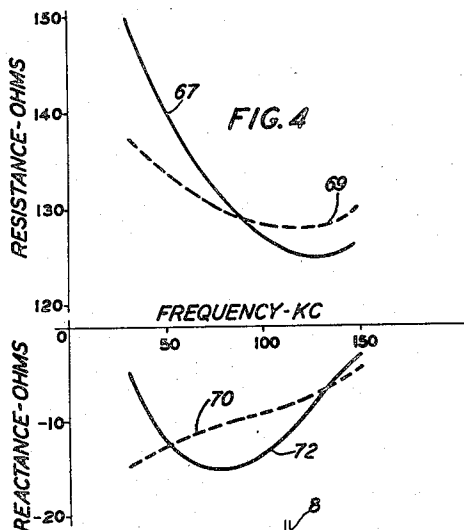
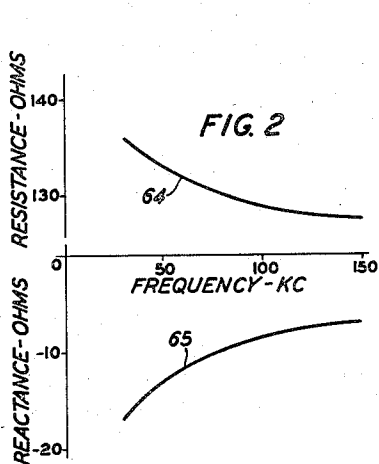
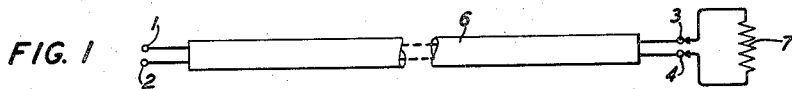
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2,163,750

HIGH FREQUENCY TRANSMISSION SYSTEM

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2 Sheets-Sheet 1



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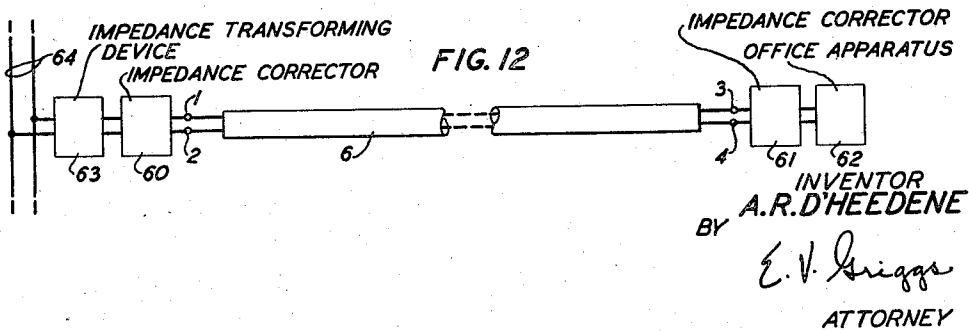
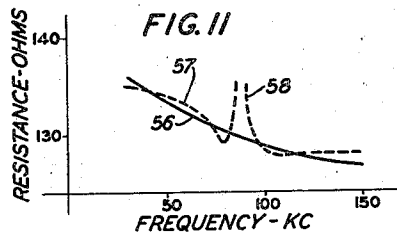
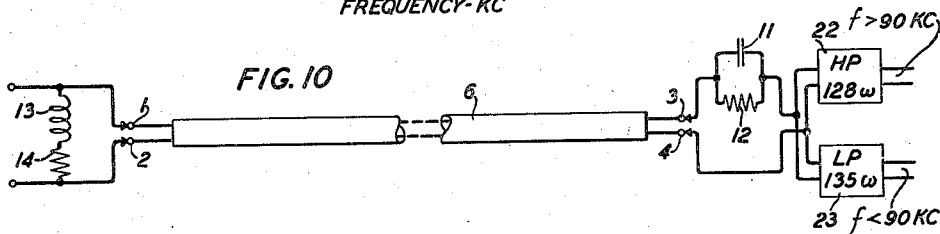
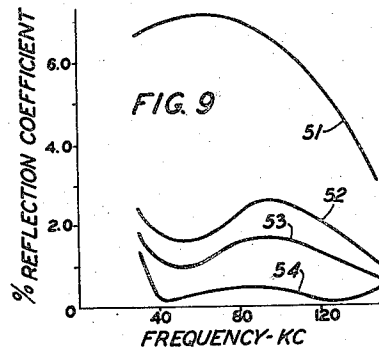
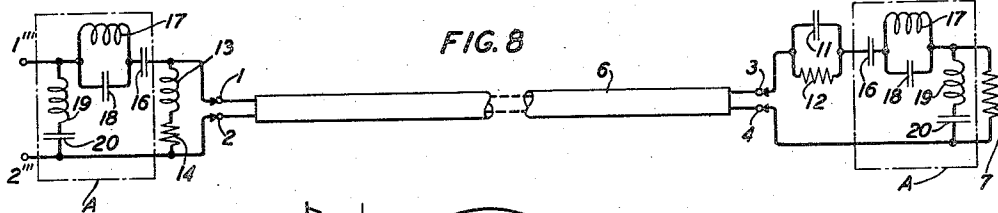
A. R. D'HEEDENE

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HIGH FREQUENCY TRANSMISSION SYSTEM

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2 Sheets-Sheet 2



UNITED STATES PATENT OFFICE

2,163,750

HIGH FREQUENCY TRANSMISSION SYSTEM

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11 Claims. (Cl. 178-44)

This invention relates to methods of and apparatus for obtaining improved transmission over non-homogeneous transmission lines. More particularly it relates to methods of and apparatus for eliminating reflections and cross-talk resulting from the junction of a section of transmission line having virtually a purely resistive impedance with a section of transmission line having a complex impedance.

10 An object of this invention is to reduce the reflection of energy occurring at the junction between dissimilar sections of a transmission line where one of the sections has substantially a constant resistive impedance and the other section has an impedance including an appreciable reactive component, which reactive component may be, moreover, of irregular character.

15 Another object of this invention is to provide methods of and apparatus for correcting impedance irregularities introduced by the insertion in a transmission system of a section of cable having low attenuation, appreciable phase shift and a substantial reactive impedance component.

20 Another object of this invention is to provide methods of and apparatus for converting a transmitting medium having low attenuation, appreciable phase shift and a substantial reactive impedance component into a medium having virtually a purely resistive impedance at one end thereof.

25 Another object of this invention is to provide methods of and apparatus for improving the impedance and transmitting properties of a transmitting medium at frequencies above those at which conventional methods of loading are practicable.

30 Another object of this invention is to provide methods of and apparatus for terminating a transmitting medium which correlate the properties of the transmitting medium with the properties of the terminating apparatus to obtain an over-all improvement in the attenuation and distortion of the medium to a wide range of "carrier" frequencies.

35 Another object of this invention is to reduce energy reflections occurring at the junction of cable circuits with open wire lines to eliminate troublesome cross-talk with adjacent open wire line circuits.

40 A further object of this invention is to simplify the problem of cross-talk reduction between adjacent open wire line circuits sufficiently that practicable transposition systems may be evolved for said circuits.

45 Other objects of this invention will become ap-

parent during the course of the description given hereinafter. The objects of this invention and the methods of attaining them may be more fully understood from the following brief description of certain communication transmission problems.

5 Since the introduction of the telegraph, a frequently employed medium in communication systems for the transmission of intelligence over long distances, has been the "open wire line" comprising a pair of parallel copper conductors supported above the earth on poles.

10 Before the advent of "carrier" communication systems the characteristics of transmission lines at frequencies above the audible range were for all practical purposes immaterial and irrelevant in communication problems. With the introduction of the first carrier telephone systems, however, line characteristics at superaudible frequencies became of vital importance.

15 The obstacles presented by line characteristics at increasingly high frequencies have, in fact, been surmounted only by dint of sustained effort in the development and improvement of many types of communication apparatus and systems. The early carrier telephone systems, for example, were confined to the use of frequencies less than 50 kilocycles by practical obstacles encountered at higher frequencies. Cross-talk between carrier systems operating on adjacent open wire lines became a serious problem at an early stage in the development of carrier telephone facilities. By evolving systems of transposing the adjacent lines (see A. G. Chapman, "Open wire cross-talk", Bell System Technical Journal, vol. 13, June 1934, pages 19 to 58, inclusive) it was possible to greatly reduce interference arising from cross-talk, provided impedance irregularities were largely eliminated.

20 That considerable progress has been made in extending the useful range of frequencies for open wire lines is evidenced by the fact that the communication system in connection with which the principles of the present invention have been evolved contemplates the use of frequencies between 30 and 150 kilocycles.

25 Carrier systems are ordinarily used to furnish communication facilities between large cities within which overhead open wire lines supported on poles have been largely replaced by cable circuits, since the latter are much less conspicuous and require much less space. One problem quite generally encountered in connection with carrier systems, therefore, has been that of providing comparatively short cable circuits which may be used to connect the terminal apparatus in the city

with open wire lines at the outskirts of the city.

A number of solutions to this problem, applicable to particular circumstances, have been employed heretofore. None of these, however, has been directed to the complete solution of the particular case in which a length of cable having low attenuation and appreciable phase shift is employed to connect the terminal apparatus and the open wire line in a system designed to operate over a wide range of frequencies such, for example, as the range between 30 and 150 kilocycles. The primary object of the present invention is, therefore, to provide methods of and apparatus for providing a low reflection coefficient between the cable and the open wire line and efficient and substantially undistorted transmission between the terminal apparatus and the open wire line over the cable circuit for the particular case last mentioned above, and other cases in which similar problems are encountered.

A better insight into the difficulties encountered may be obtained by briefly considering the nature and scope of prior methods employed in adapting cable circuits to operate with open wire lines and the particular circumstances under which they are applicable.

Because of differences in the geometrical arrangement of the conductors and the physical dimensions and electrical properties of the dielectrics employed, cable circuits in general tend to have lower characteristic impedance and much greater capacity between conductors than open wire line circuits. Whereas the latter, for many purposes, may be assumed to have purely resistive impedance, the majority of cable circuits have reactive impedance components which may not be ignored without detriment to the transmission qualities of the circuit in many cases.

One obvious and commonly employed method of improving the impedance match between a cable circuit and an open wire line is to introduce at the junction a transformer having the proper ratio to "step up" the cable impedance to that of the open wire line. This, however, does not make any correction for the reactive component of the cable impedance.

Prior means employed to compensate for the effects of the reactive properties of the cable have consisted of loading the cable by introducing series inductance.

A serious problem presented in such loading schemes is that of obtaining reasonably uniform distribution of the loading units along the cable circuit, particularly since in many cases the cables are underground and access to them may be had only at a few points. The additional expense and the inconvenience of splicing in loading units at numerous points along the cable also must be considered in the application of loading schemes. A number of compromise schemes which approximate the effect of uniform loading and partially realize its benefits by introducing modified loading elements at relatively few points have been suggested to avoid the objections last mentioned.

Also, since practicable loading systems produce a sharp "cut-off" point at a relatively low frequency, they cannot be employed with systems transmitting frequencies as high as those contemplated in connection with the present invention.

The present invention is directed principally, therefore, to the solution of a problem which has been either entirely ignored or considered to be of negligible importance in connection with the

systems contemplated in connection with the prior inventions but it becomes of real importance in systems now being contemplated. The principal reasons for this are that the range of frequencies now being contemplated is, as above stated, appreciably higher; that the lengths of cable circuits involved are neither so short that phase shift may be neglected nor so long that reflection effects from the far end of the cable circuit are sufficiently reduced by the attenuation of the cable circuit to be negligible and that in the present invention the transmission characteristics at comparatively low frequencies, especially at voice frequencies, may be entirely neglected since it is not contemplated that they will be employed. The success of the entire system hinges, in the present invention, upon eliminating the reflections which would result were the reactive component of the cable impedance not taken into consideration, since the reflections then resulting would make it impossible to evolve a practicable transposition system which would effectively eliminate cross-talk between adjacent open wire lines.

Bearing in mind the above considerations, the methods of this invention involve essentially the elements described hereunder. The first of these comprises the termination of the cable circuit at its office or "far" end in its own characteristic impedance to avoid reflection from that end. This is essential for if reflections of appreciable magnitude were permitted at the far end they would, upon arriving back at the near end, produce an undulating, or irregular, near end impedance characteristic which it would not be possible to correct by any practicable reactive network. At the line or "near" end of the cable circuit the second element is introduced and comprises the annulling of the reactive component of the cable circuit impedance by bridging a conjugate reactive device across its near end terminals. This leaves substantially the purely resistive component of the cable circuit impedance. As a third element, the cable circuit may then be coupled to the open wire line through a transformer, an autotransformer, or other impedance transforming network of suitable impedance ratio so that only a small impedance irregularity and consequently only a small energy reflection will occur at the junction of the cable circuit and the open wire line. Further refinements representing a possible fourth element which may be employed in connection with this invention comprise the introduction of networks which transform the resistive component of the cable impedance into a virtually constant resistance over the frequency range to be used, as will be subsequently explained in more detail.

The detailed features of the invention may be more readily understood from the following description when read in connection with the accompanying drawings of which:

Fig. 1 represents a section of cable terminated at the office end, or far end, by a constant resistance representing the input impedance of the terminal apparatus;

Fig. 2 shows the resistive and reactive components of the characteristic impedance of a cable circuit of the type illustrated in Fig. 1;

Fig. 3 illustrates a simple form of impedance correction which may be employed to improve the impedance of a cable circuit of the type illustrated in Fig. 1;

Fig. 4 shows the actual impedance of the cir-

cuit of Fig. 1 and the improvement effected by the modification indicated in Fig. 3;

Fig. 5 illustrates a more refined form of impedance correction which may be employed to improve the impedance of a cable circuit of the type illustrated in Fig. 1;

Fig. 6 contrasts the reactive components of the cable circuit impedance after the corrective steps indicated in Figs. 3 and 5, respectively, have been taken with the reactive component of the cable's characteristic impedance;

Fig. 7 contrasts the susceptances obtained by the corrective steps indicated in Figs. 3 and 5, respectively, with the susceptance required to annul the reactive component of the cable's characteristic impedance;

Fig. 8 illustrates a method of converting the cable resistance to a substantially constant resistance over a wide range of frequencies;

Fig. 9 illustrates the successive improvement of the reflection coefficient between the cable circuit and the open wire line effected by the corrective steps indicated in Figs. 3, 5 and 8, respectively;

Fig. 10 shows a method of terminating the office end of the cable circuit in a plurality of grouping or directional filters having different characteristic impedances;

Fig. 11 illustrates how the arrangement of Fig. 10 provides an improved impedance match over the useful ranges of frequencies; and

Fig. 12 illustrates in block schematic form a complete system of this invention.

In Fig. 1, cable 6 represents the cable circuit of the type mentioned above, that is, a circuit having low attenuation, appreciable phase shift and a characteristic impedance which includes a reactive component of sufficient magnitude that it may not be neglected without introducing undesirable impedance irregularities in the transmission system with which it is to be employed. In Fig. 1 the line end terminals have been designated as terminals 1 and 2 and the office end terminals as terminals 3 and 4. Resistive impedance 7 represents the impedance of the equipment connected to the cable circuit at the office end. Like designations have been employed in the subsequent figures for these elements.

The resistive and reactive components of the characteristic impedance of a section of cable, such as is contemplated in Fig. 1 are shown in Fig. 2 by curves 64 and 65, respectively. As stated above, in order to obtain essentially the characteristic impedance of the cable at its line end, that is, across terminals 1 and 2, it is necessary that the impedance connected across terminals 3 and 4 should simulate the characteristic impedance of the cable.

Fig. 3 represents a first approximation to the last-mentioned condition. Condenser 8 in series with the resistive impedance 7 may be designed to approximate the characteristic impedance of the cable circuit 6, as illustrated by the approximation of curve 73 to curve 76 in Fig. 6, curve 73 representing the impedance of the first-mentioned combination and curve 76 representing that of cable 6.

In Fig. 4 curves 67 and 72 represent the resistive and reactive components, respectively, of the impedance obtained at terminals 1 and 2 of cable circuit 6 when terminals 3 and 4 connect directly to resistive impedance 7 as shown in Fig. 1. Curves 69 and 70 of Fig. 4 show the improvement in the impedance obtained at terminals 1 and 2 by adding condenser 8 as shown in Fig. 3.

The increased regularity of the impedance components thus obtained greatly facilitates the solution of the problem of impedance correction.

The next step in improving the cable circuit impedance is to annul the reactive component indicated by curve 70 of Fig. 4. This may be done by connecting in shunt across terminals 1, 2 of the cable circuit 6 a conjugate reactance. Since the reactance represented by curve 70 of Fig. 4 approximates that of a simple capacity, its conjugate can be approximated by an inductive reactance indicated as coil 9 shown in Fig. 3. The degree of approximation is indicated by the similarity between curves 78 and 79 of Fig. 7, curve 78 representing the susceptance required for perfect annulment and curve 79 representing the susceptance of coil 9. At terminals 1', 2' of Fig. 3 we then obtain an impedance which will be approximately the purely resistive impedance represented by curve 69 of Fig. 4.

The impedance correction of cable circuit 6 may be further improved by employing two element corrective networks as illustrated in Fig. 5. Curve 75 of Fig. 6 and curve 81 of Fig. 7 illustrate the respective closer approximations obtained by the use of the combinations comprising capacity 11 and resistance 12 at the office end and coil 13 and resistance 14 at the line end.

That is, curve 75 of Fig. 6 indicates by its closer proximity to curve 76 of Fig. 6 that a better impedance match may be obtained at cable terminals 3, 4 by adding a condenser 11 in parallel with a resistance 12, the combination being in series with the resistive impedance 7 as shown in Fig. 5, in place of a simple condenser 8 as shown in Fig. 3. Similarly, at terminals 1, 2 of cable circuit 6 a coil 13 in series with a resistance 14 employed in shunt as shown in Fig. 5, rather than a simple coil 9 as shown in Fig. 3, will provide a closer approximation to the desired susceptance as illustrated by the closer proximity of curve 81 of Fig. 7 to curve 78 of that figure.

Still closer approximations may obviously be obtained by employing still more complex networks designed in accordance with well-known network theory to provide the desired characteristics.

A second consideration, namely the variation of the resistive component of the cable circuit with frequency as illustrated for example by curve 69 of Fig. 4, may be taken into account by inserting a network designated as A in Fig. 8 whose resistive impedance at one end matches that of the cable circuit over the frequency range to be employed and whose resistive impedance at the other end is substantially constant with frequency over this same frequency range. The network may be considered in the nature of a device for transforming a resistive characteristic which varies with frequency into a resistive characteristic which is substantially constant with frequency over a particular frequency range. In this particular case, it happens that a half section high-pass filter having a double M derived mid-series impedance at one end and a mid-shunt single M derived impedance at the other end proves very satisfactory. The design of single M and double M derived wave filters is discussed by O. J. Zobel in the Bell System Technical Journal for January 1923 and April 1931, respectively. The inductances of coils 17 and 19 and the capacities of condensers 16, 18 and 20 of the network A in Fig. 8 are determined in accordance with the principles and formulae given

in the above-mentioned papers. Incidentally, in U. S. Patent 1,828,454 issued October 20, 1931 to H. W. Bode, an alternative and somewhat more generally applicable method whereby wave filters (i. e. substantially non-dissipative networks) may be designed to provide a desired constant resistive impedance over the transmitting frequency range of the filter is given in detail. While Bode applies the method in the above-mentioned patent to the problem of obtaining a constant resistive impedance it may obviously be equally well applied to the problem of obtaining a resistive impedance which will vary in accordance with any one of a large number of resistive characteristics, which vary with frequency over a broad range of frequencies in particular desired manners. The single M and double M derived structures of Zobel as disclosed in the above-mentioned papers may be regarded as, in essence, special examples of the more general case covered by Bode's method. As such networks in whatever manner they may be derived, comprise sections of wave filters the coils and condensers including those of network A of Fig. 8, should ideally be purely reactive, in which event the network will not dissipate any energy. In practice, of course, some dissipation must be present since the best known conductors have some resistance and the best known condenser dielectrics entail some energy losses. However, by well-known methods of construction "substantially dissipationless" networks, that is networks in which only a very small percentage of the energy passing through them is dissipated, can be made.

A convenient index of the magnitude of reflection effects occurring at the junction of two circuits having impedances Z_1 and Z_2 , respectively, is the commonly used reflection coefficient which is defined as the difference divided by the sum of the absolute values of the impedances involved. The progressive improvement obtained by the impedance corrective measures shown in Figs. 3, 5 and 8 over the uncorrected cable circuit as shown in Fig. 1, is illustrated in Fig. 9 where curves 51, 52, 53 and 54 show the respective reflection coefficients corresponding to the arrangements of Figs. 1, 3, 5 and 8, respectively.

Fig. 10 illustrates an alternative method of obtaining a good match between the resistive component of the cable circuit 6 and that of the office equipment which consists of employing a high-pass and a low-pass filter connected in parallel at the cable circuit end, but connecting to independent circuits at their respective office ends. The characteristic impedance of each filter is so chosen that its resistive component will match closely the resistive component of the cable circuit over the range of frequencies transmitted by that particular filter and its termination at the paralleling end is so chosen that it will have a complementary effect upon the other filter over the latter's transmitting range of frequencies. The principles involved are similar to those described and explained in U. S. Patent 1,557,230 to O. J. Zobel issued October 13, 1925, except that in this case the two filters are given different characteristic impedances so that their resistive components will better match the resistive components of the cable circuit impedance over its particular transmitting range of frequencies. For example, in the present case, low-pass filter 23 is given a characteristic impedance of 135 ohms whereas high-pass filter 22 is given a characteristic impedance of 128 ohms. The degree of impedance match obtained by this arrange-

ment is illustrated in Fig. 11, curve 56 being the resistive component of the cable circuit impedance, curve 57 being the resistive component of the low-pass filter 23 and curve 58 being the resistive component of the high-pass filter 22. This arrangement is of considerable practical importance since in many carrier systems it is desirable to divide the available frequency range into two regions, usually for transmission in opposite directions. The arrangement requires the sacrifice of a small interval of frequencies between the two useful ranges, commonly known as the cross-over interval, in which the high and low-pass filters, commonly known as directional filters, may attain sufficient discrimination against that range of frequencies which the filter is designed to suppress. The reflection coefficient obtained over this cross-over interval naturally need not be held within as close limits as is desirable over the useful ranges of frequency. Identical principles may obviously be employed if it is desirable to divide the useful range of frequencies into more than two parts.

Having obtained at the line end of the cable circuit an impedance approaching within acceptable limits a constant resistance of convenient value, it is then only necessary to insert an impedance transformer having the proper ratio to match this substantially constant resistance to that of the open wire line. The complete system of this invention then becomes that shown in the block diagram of Fig. 12 in which block 62 represents the office equipment, block 61 represents impedance correcting devices inserted between the office end of the cable circuit 6 and the office equipment, block 60 represents impedance corrective devices inserted at the line end of the cable circuit 6 and block 63 represents transforming means inserted to transform the substantially constant resistive impedance obtained at the line end of the device 60 to match the substantially constant resistive impedance of the open wire line 64.

Many other applications and modifications within the spirit and scope of the invention will occur to persons skilled in the art and no effort has here been made to be exhaustive.

What is claimed is:

1. In a transmission system a section of cable having low attenuation, appreciable phase shift and a substantial reactive impedance component, the far end of said cable being terminated in its characteristic impedance, the near end of said cable being terminated by a shunting reactance and a high-pass filter, said shunting reactance being designed to annul the reactive component of the near end cable impedance and said filter being designed to match the resistive component of the near end cable impedance, the impedance of the free end of said filter being of substantially constant resistance over a range of frequencies in which the resistive component of said cable varies appreciably, whereby a small reflection coefficient may be obtained over a wide range of frequencies when said cable circuit is connected to a circuit having a constant resistance over said frequency range.

2. In a communication system a transmission line having a substantially constant resistive impedance, a second transmission line having a resistive characteristic which varies with frequency over the useful frequency range of said system and a substantially non-dissipative electrical network inserted between said two transmission lines, said network transforming the re-

sistive characteristic of said second line into a constant resistance equalling that of said first line whereby impedance irregularities at the junction of said lines are substantially reduced.

3. In a communication system a cable circuit arranged to connect office apparatus with a transmission line, a condenser electrically in series relation with said apparatus at the office end of said cable and an inductance electrically in shunt with said cable at the line end thereof, said condenser serving with the office apparatus to match the characteristic impedance of said cable at the office end, said inductance serving to annul the reactive component of the cable impedance at the line end.

4. In a carrier communication system, a transmitting medium comprising a circuit having a substantially constant resistive impedance connecting to a circuit having low attenuation, appreciable phase shift and a reactive characteristic impedance component of troublesome magnitude, a first impedance modifying device at the far end of said second circuit, said first device combined with the normal load at the far end of said second circuit closely simulating the characteristic impedance of said second circuit, a second impedance modifying device at the near end of said second circuit, said second impedance modifying device neutralizing and annulling the reactive component of the characteristic impedance of said second circuit and a third impedance modifying device, said third impedance modifying device being substantially non-dissipative and changing the resistive component of the near end impedance of said second circuit from that of a resistance which varies with frequency to that of a resistance which has a substantially constant value over a wide range of frequencies whereby the first said circuit may be connected with the second said circuit without substantial reflection or dissipation of energy.

5. A system as defined in claim 4 and a fourth impedance modifying device, said fourth impedance modifying device being substantially non-dissipative and changing the resistive component of the far end impedance of said second circuit from that of a resistance which varies with frequency to that of a resistance which has a substantially constant value over a wide range of frequencies whereby the normal load connecting to the far end of said second circuit may be designed to have a constant resistive impedance over said wide range of frequencies.

6. In a carrier communication system, an open wire line having a substantially constant and purely resistive impedance over a wide range of frequencies, terminal office apparatus likewise having a substantially constant and purely resistive impedance over the same wide range of frequencies, a cable circuit having low attenuation, appreciable phase shift and a characteristic impedance which includes a reactive component of troublesome magnitude and a resistive component which varies substantially over the said wide range of frequencies, an impedance correc-

tive network and a wave filter at each end of said cable circuit, said cable circuit through said networks and wave filters at its respective ends serving to connect said terminal office apparatus with said open wire line, the said impedance corrective networks serving to smooth out the impedance of said cable circuit and to annul the reactive component of said cable circuit impedance and said wave filters being substantially non-dissipative and serving to transform the variable resistive component of said cable circuit impedance into a substantially constant resistance over the said wide range of frequencies whereby the said terminal office apparatus may be connected to the said open wire line through the medium of said cable circuit without substantial reflection or dissipation of energy throughout said wide range of frequencies.

7. The system of claim 6, each of said wave filters having a double M derived terminating section at one end and a single M derived terminating section at the other end.

8. The system of claim 6, each of said wave filters having a multiple M derived terminating section at one end and a single M derived terminating section at the other end.

9. The method of correcting the impedance of a telephone cable which comprises as a first step eliminating irregularities in said impedance, as a second step annulling the reactive component of said impedance and as a final step the substantially dissipationless transformation of the frequency-variable resistive component of said cable into a constant resistance with frequency.

10. The method of correcting the impedance of a communication circuit, said circuit having low attenuation, appreciable phase shift, a resistive characteristic impedance component varying substantially over the frequency range of interest, and a substantial reactive characteristic impedance component, said method comprising, eliminating irregularities in said impedance at the near end of said circuit by matching the impedance at the far end thereof, annulling the reactive component of said near-end impedance and transforming, with substantially no dissipation, the variable resistive component of said near end impedance into a resistive component which is constant with frequency.

11. In combination with a communication circuit having low attenuation, appreciable phase shift and a characteristic impedance comprising a resistive component varying substantially over the frequency range of interest and a reactive component of substantial magnitude over said frequency range, means for eliminating irregularities in said impedance components as they appear at one end of said circuit means at said end of said circuit for annulling said reactive component and means comprising a substantially dissipationless network for transforming said variable resistive component into a component which is substantially constant with frequency over said frequency range.

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