CARRIER CURRENT APPARATUS

Filed March 7, 1942 3 Sheets-Sheet 1

Fig. 1.

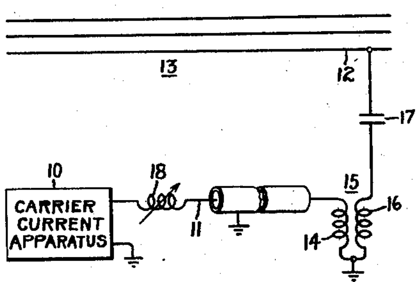


Fig. 2.

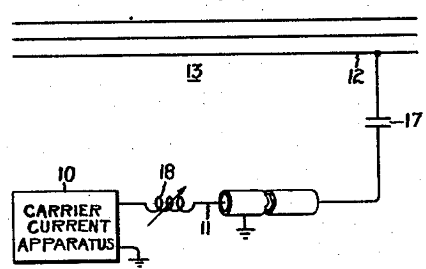


Fig. 3.

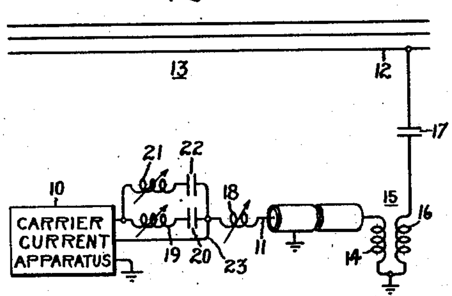
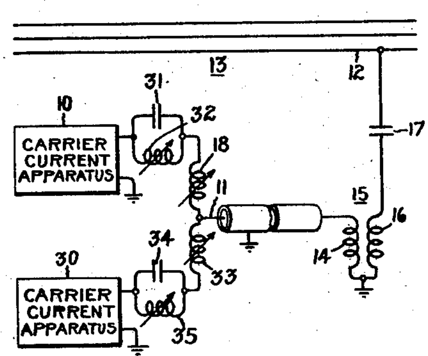


Fig. 4.



Inventor:
Edwin W. Kenefake,
by Harry E. Dunham
His Attorney.

Dec. 7, 1943. E. W. KENEFAKE 2,336,258

CARRIER CURRENT APPARATUS

Filed March 7, 1942 3 Sheets-Sheet 2

Fig. 5.

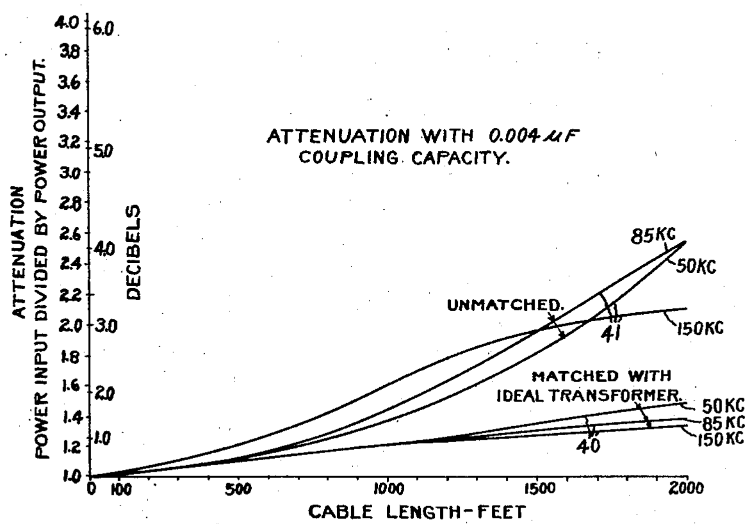
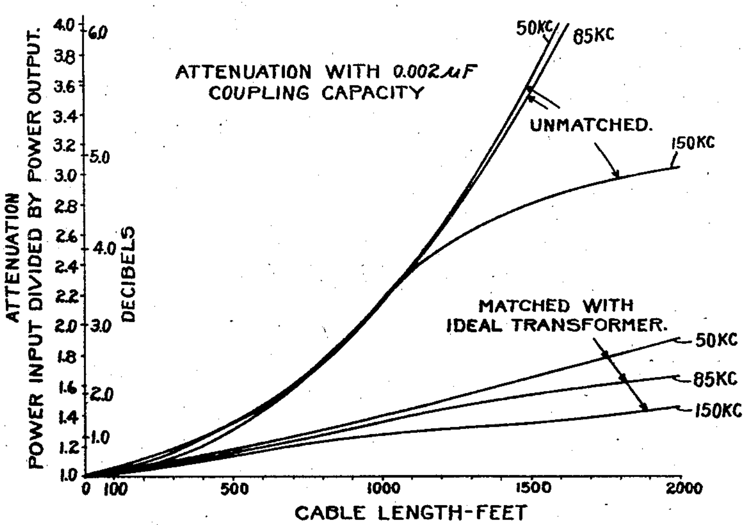


Fig. 6.



Inventor:
Edwin W. Kenefake,
by Harry E. Dunham
His Attorney.

Dec. 7, 1943. E. W. KENEFAKE 2,336,258

CARRIER CURRENT APPARATUS

Filed March 7, 1942 3 Sheets-Sheet 3

Fig. 7.

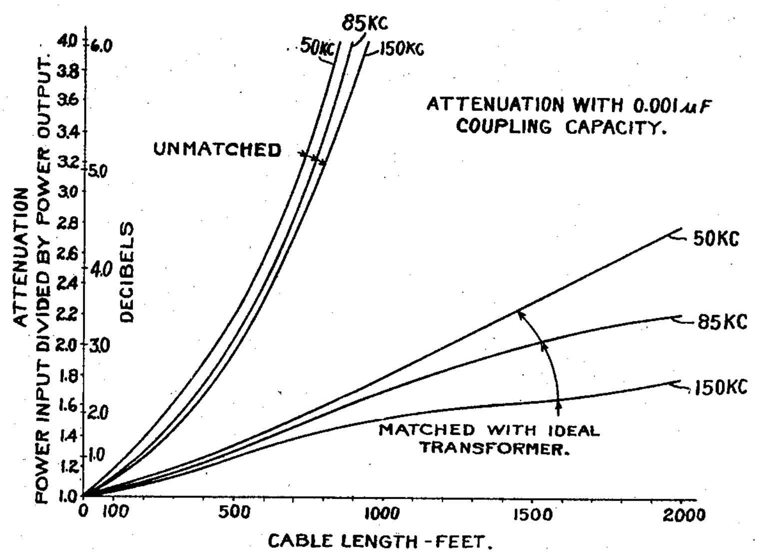
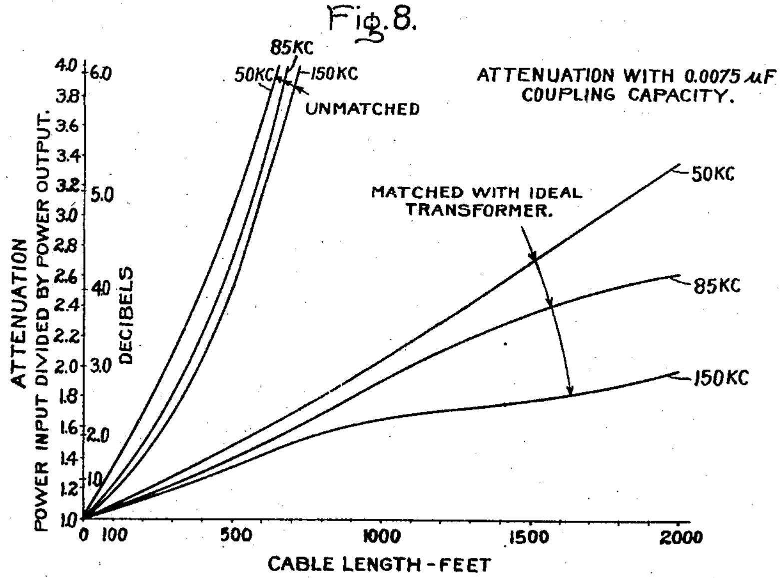


Fig. 8.



Inventor:
Edwin W. Kenefake,
by Harry E. Dunham
His Attorney.

Patented Dec. 7, 1943

2,336,258

UNITED STATES PATENT OFFICE

2,336,258

CARRIER CURRENT APPARATUS

Edwin W. Kenefake, Schenectady, N. Y., assignor to General Electric Company, a corporation of New York

Application March 7, 1942, Serial No. 433,824

5 Claims. (Cl. 177—352)

My invention relates to carrier current apparatus, and more particularly to means for coupling carrier current transmitters and receivers with power transmission lines.

It has generally been considered expedient to connect carrier current apparatus to high voltage power transmission lines through coupling capacitors. When such coupling capacitors are used, it is most efficient to provide means for tuning the transmission line and the coupling capacitor so that the transmission line system presents a purely resistive impedance to the carrier current apparatus. Such an arrangement is satisfactory from an operating standpoint where the carrier current apparatus is in close proximity to the power transmission line since tuning means for the coupling capacitor and transmission line may then be in the same enclosure as the carrier current apparatus and is thus readily accessible for easy adjustment without special precautions to protect it from the weather.

In many cases carrier current apparatus is located at a considerable distance from the power transmission line, making it necessary to use a signal transmission line, such as a coaxial cable, to transmit signals between the carrier current apparatus and the power transmission line. Where such a signal transmission line has been utilized, it has been the practice in the past to provide tuning means and impedance matching means both between the carrier current apparatus and the signal transmission line and between the signal transmission line and the power transmission line.

In such systems a coupling capacitor is used to insulate the signal transmission line from the power transmission line, and an inductance is provided in series with the coupling capacitor between these two lines to tune the capacitor and power line to series resonance at the signal frequency. There is also provided a transformer for matching the characteristic impedance of the signal transmission line to the impedance of the coupling capacitor and power transmission line, so as to provide for the maximum transfer of signals therebetween. A similar tuning means and transformer has been used between the signal transmission line and the carrier current apparatus. These tuning and impedance matching means have reduced attenuation to the low levels.

It is an object of my invention to provide in such systems requiring a signal transmission line improved and simplified connecting means between the carrier current apparatus and the power transmission line to which it is connected.

It is a further object of my invention to provide such improved connecting means which requires a minimum of adjustment and maintenance except at the carrier current apparatus.

It is another object of my invention to provide such improved and simplified connecting means including a signal transmission cable between carrier current apparatus and the power transmission line, which means requires a minimum of space and a minimum investment and which is rugged and reliable in operation.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, both as to its organization and manner of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings in which Figs. 1, 2, 3 and 4 illustrate four modifications of my invention and Figs. 5, 6, 7 and 8 are graphical representations of the various characteristics thereof.

In Fig. 1 a carrier current apparatus 10, which may conveniently include a carrier current transmitter and a carrier current receiver, is connected, through coupling means including a signal transmission line 11, between ground and one conductor 12 of a power transmission line 13. The signal transmission line 11 may conveniently be the center conductor of a coaxial transmission line, of which the outer conductor is grounded. At that end of the transmission line 11 adjacent the power transmission line 13, the line 11 is connected through one winding 14 of a transformer 15 to ground. One terminal of the other winding 16 of the transformer 15 is grounded, and the other terminal is connected through a suitable coupling capacitor 17 to the conductor 12 of the power transmission line 13.

An adjustable inductance 18 is connected between the carrier current apparatus 10 and the signal transmission line 11, and is so adjusted as to be series resonant with the capacitive impedance of the system including the signal transmission line 11, the transformer 15, the coupling capacitor 17 and the power transmission line 13.

The windings 14 and 16 of the transformer 15 have a turn ratio equal to the square root of the ratio of the impedance of the power transmission line 13 as measured through the condenser 17 to the characteristic impedance of the signal transmission line. That is, the square of the number of turns in the winding 16 corresponds to the impedance of the power transmission line 13, as measured through condenser 17, in the same way as the square of the number of turns of the winding 16 corresponds to the characteristic impedance of the signal transmission line.

Such a relation between impedances and turn ratio of the transformer 15 is desirable because attenuation in a transmission line is minimum when it is connected at its ends to devices whose impedance, including both resistance and reactance, is equal to the characteristic impedance of the transmission line. While it is true that such attenuation may be further minimized by making the impedance of the connected devices purely resistive, it has been found that the attenuation is satisfactorily low even though reactance be present, if impedances are matched, as stated above. The characteristic impedance of the transmission line need not be matched exactly, as the attenuation does not increase rapidly as the connected impedances vary from a value equal to the characteristic impedance of the line.

In a typical example, where a coaxial cable of 70 ohm characteristic impedance is selected as the transmission line, the carrier current apparatus operates at 100 kilocycles and the coupling condenser 17 has a capacity of 0.002 microfarad, the impedance of the power line 13 may be assumed to be 400 ohms of pure resistance, and the impedance to which the transmission line must then be matched is 882 ohms. The impedance ratio is then 12.6 and the turn ratio of transformer 15 is 3.4.

It has been determined that the elements shown in Fig. 1, adjusted as described above, may be utilized for the efficient transmission of signals between the carrier current apparatus 10 and the power transmission line 13 with reasonably small attenuation through the signal transmission line 11 over substantial distances. The actual relation between attenuation through the signal transmission line 11 and the length of that line is set forth hereinafter for certain situations encountered in practice.

In Fig. 2 the carrier current apparatus 10 is connected through the inductance 18, and the transmission line 11 directly to one terminal of the coupling condenser 17, whose other terminal is connected to the conductor 12 of the power transmission line 13. The inductance 18 is in this case adjusted so that the whole system including the inductance 18, the transmission line 11, condenser 17, and the power transmission line 13 is resonant at the signal frequency. When this arrangement of elements is used, omitting the impedance matching transformer 15 of Fig. 1, there is somewhat more signal reflection and consequently greater attenuation through the signal transmission line 11. It has been found, however, that even such greater attenuation is reasonably small over some distances, and, in fact, not intolerably large. The relation between attenuation and the length of the signal transmission line 11 for this arrangement of elements in Fig. 2 is also set forth hereinafter for certain situations encountered in practice.

The apparatus illustrated in Figs. 3 and 4 are modications of the arrangement illustrated in Fig. 1. In Fig. 3 the carrier current apparatus 10 is arranged for operation at two different frequencies. For example, the carrier current apparatus 10 may include a transmitter operative at one frequency, and a receiver operative at a different frequency. The transmitter in the apparatus 10 is connected to the adjustable inductance 18 and transmission line 11 through two paths, one of which includes an inductance 19 and condenser 20 in series, and the other of which includes an inductance 21 and condenser 22 in series. The receiver in the apparatus 10 is connected through a conductor 23 to a point between the condensers 20 and 22 and the inductance 18.

The arrangement of such a transmitter and receiver together with means for coupling them to the power transmission line 13 including inductances 18, 19 and 21 and condensers 17, 20 and 22 forms no part of the present invention, and is described and claimed in my application for United States Letters Patent, Serial No. 357,274, filed on Sept. 18, 1940, for Coupling apparatus, and assigned to the same assignee as the present application.

Briefly, the adjustment of these elements is as follows. The inductance 19 is adjusted to resonate in series with the condenser 20 at the transmitter frequency, and the inductance 18 is adjusted to resonate with the condenser 17 and other capacities in the system at the same transmitter frequency. The connections between the transmitter of the apparatus 10 and the power transmission line 13 are series resonant at the transmitter frequency and present a low impedance to the transmission of carrier current signals from the apparatus 10 to the transmission line 13.

At the frequency to be received, the two series paths, one including the transmitter in the apparatus 10, the inductance 19 and condenser 20, and the other including the inductance 18 and condenser 17, exhibit inductive or capacitive reactance, depending on whether the receiver frequency is higher or lower, respectively, than the transmitter frequency. The overall reactance of the series path including the adjustable inductance 21 and condenser 22 is adjusted to such a value that the total reactance of the group including the transmitter, the inductances 19 and 21 and the condensers 20 and 22 is equal in value, and opposite in character, to the reactance of the remainder of the path from the apparatus 10 to the power line 13, such path including the adjustable inductance 18 and condenser 17. The inductance 18 and condenser 17 therefore form one branch of a series tuned circuit, the other branch being formed by the transmitter in the apparatus 10, the inductances 19 and 21 and the condensers 20 and 22, so that the potential at a point between these two branches tends to rise to a high value at the receiver frequency. The conductor 23 which is connected to such point therefore transmits such high potential to the receiver in the apparatus 10.

In other respects the apparatus illustrated in Fig. 3 performs in a fashion similar to that illustrated in Fig. 1, and provides efficient transfer of signals with small attenuation over substantial lengths of signal transmission line 11 between the apparatus 10 and the power transmission line 13. The data presented hereinafter correlating such attenuation and line lengths for Fig. 1 is equally applicable for Fig. 3.

Heretofore, the connection shown in Fig. 3 and described in the above mentioned application has been used only where the carrier current apparatus has been so near the power line 13 that a transmission line has not been needed, since only in such arrangements could the connection 23 be made to a point between the coupling condenser 17 and the adjacent tuning inductances and condensers 18, 19, 20, 21 and 22. Now, however, by the use of the simplified arrangement of Fig. 3, these inductances and condensers 18, 19, 20, 21 and 22 are placed adjacent the carrier current apparatus, the attenuation through transmission line 11 being satisfactorily small, and the connection 23 may easily be made, thereby resulting in more efficient operation of the receiver, as well as easier adjustment and maintenance of the apparatus as a whole.

In Fig. 4 the transmission line 11, transformer 15 and condenser 17 are utilized to transfer carrier current signals between the power transmission lines 13 and two carrier current apparatus, including the apparatus 10 and another apparatus 30. Each such apparatus may include a carrier current transmitter, and a receiver operating at the same frequency, each apparatus as a whole being operative at a different frequency.

The apparatus 10 is connected to the adjustable inductance 18 and transmission line 11 through a condenser 31 shunted by an adjustable inductance 32. The apparatus 30 is connected to a point between the inductance 18 and transmission line 11 through a path serially including an adjustable inductance 33 and a shunt combination of a condenser 34 and an adjustable inductance 35.

The adjustment of the apparatus of Fig. 4 is as follows. The parallel tuned circuit including the condenser 31 and inductance 32 is made parallel resonant at the frequency of the apparatus 30. Similarly, the parallel circuit including condenser 34 and inductance 35 is made parallel resonant at the operating frequency of the apparatus 10. The inductance 18 is then adjusted so that the apparatus 10, inductance 32, condenser 31, inductance 18, transmission line 11, transformer 15, coupling condenser 17, and the power line 13 are resonant at the operating frequency of the apparatus 10. At this frequency the parallel resonant circuit including condenser 34 and inductance 35 offers a high impedance so that signals transferred between apparatus 10 and the power line 13 are not dissipated in the apparatus 30.

In similar fashion, the inductance 33 is adjusted so that the apparatus 30, the inductance 35, condenser 34, the inductance 33, the transmission line 11, transformer 15, coupling condenser 17, and power line 13, are all resonant at the frequency of operation of the apparatus 30. At this frequency the circuit including condenser 31 and inductance 32 offers a high impedance so that signals transferred between the power line 13 and apparatus 30 are not dissipated in the apparatus 10. Insofar as the present invention is concerned, the apparatus 10 and 30 respectively cooperate with the inductances 18 and 33, and with transmission line 11, transformer 15, coupling condenser 17 and the power transmission line 13 in the same way as corresponding elements in the apparatus of Fig. 1. The relation between attenuation and signal transmission line length is the same as that set forth hereinafter for Fig. 1.

While the apparatus in Figs. 1 through 4 has been illustrated as impressing a signal between a single conductor 12 of the power line 13 and ground, it is within the scope of my invention to duplicate the illustrated connecting equipment so that the grounded terminals of the carrier current apparatus may in each case be connected, instead of to ground, to a second conductor of the power transmission line 13.

In many situations it is entirely satisfactory to ground one terminal of a carrier current apparatus, where the attenuation caused by such connection is not unduly great. By connecting the two terminals of the carrier current apparatus to two different conductors of the power line 13, signals may be transmitted through the power line 13 with somewhat less attenuation, so that longer transmission distances may be achieved.

In the case of the apparatus illustrated in Figs. 1, 3 and 4, it is not necessary to duplicate all the equipment for connecting the carrier current apparatus to the power line 13, since in each case, the two terminals of the secondary 16 of transformer 15 may be connected through separate coupling condensers to two different conductors of the power line 13. In other respects the apparatus for interphase transmission may be exactly the same as that illustrated in Figs. 1, 3 and 4.

One of the conditions to be considered in determining how a simplified arrangement according to my invention may be utilized is the capacity of the coupling condenser 17. This capacity to a substantial extent determines the reactance presented to the end of the transmission line 11 adjacent the power line 13, and hence is important in considering how much attenuation may be produced through the transmission line 11. In all cases hereinafter considered, it is assumed that the impedance between one conductor 12 of the power line 13 and ground is 400 ohms, which value is substantially correct for any transmission line. Although power transmission lines may have a somewhat higher impedance, the impedance is primarily resistive and consequently higher impedance lines reduce attenuation losses in the transmission line 11 and make the resulting operation more efficient.

As a practical matter, the capacity of the coupling condenser 17 is determined primarily by the amount of insulation it must afford between the conductor 12 and ground. That is, the higher the voltage of the power line 13, the more insulation there must be between the capacity elements of the condenser 17, and consequently the less the capacity of the condenser 17. At the present time certain sizes of condensers are available for use as coupling condensers on power lines of particular voltages, as indicated in the following tabulation:

Line voltage, kv.	Number condensers in series	Capacity for condenser, μf.	Total capacity μf.
34.5	1	.006	.006
69	1	.003	.003
115	2	[1].003/.006	.002
138	2	.003	.0015
161	3	[1].006/.003	.0012
230	3	.003	.001
287	4	.003	.00075
375	5	.003	.0006

[1] In these cases one condenser of the first size is used, and one or two of the second size as needed to complete the necessary number. Thus, for 161 kv. 1 condenser of .006 μf. and 2 condensers of .003 μf. are used.

In Fig. 5 values of attenuation between the carrier current apparatus 10 and the power line 13 are plotted as ordinates against corresponding lengths of the transmission line 11, plotted as abscissae, for several conditions of operation of the apparatus of Figs. 1 through 4. All the curves of Fig. 5 are based upon the use of a coupling condenser 17 whose capacity is 0.004 microfarad. The three curves 40, accompanied by the legend "Matched with ideal transformer," represent the attenuation associated with the arrangements of Figs. 1, 3 or 4 at three different operating frequencies, as indicated. The three curves 41 indicate the attenuation associated with the arrangement of Fig. 2 at three different operating frequencies, as indicated.

Although attenuation is substantially greater when the transformer 15 is not used, as illustrated by the curves 41, the attenuation which is realized when neither the transformer 15 nor tuning apparatus adjacent the condenser 17 is utilized is reasonably small even though transmission line 11 is as much as 1000 ft. long. The attenuation realized when the transformer 15 is utilized, as indicated by the curve 40, is even smaller and is well within usable limits for cable lengths greater than 2000 ft., even though no tuning device is used adjacent the condenser 17.

For purposes of the general discussion herein, it has been assumed that there should be no more than two decibels attenuation between the carrier current apparatus 10 and the power line 13 for satisfactory operation. Certain operating considerations may change this value to some extent in certain particular situations. Carrier current apparatus, as generally utilized at the present time, is capable of producing about 50 decibels gain in a received signal when the automatic volume control voltage is smallest. The total attenuation between carrier current transmitter and receiver must, therefore, never exceed this value, even under the worst conditions of weather and the like.

Accordingly, it is common practice to assume that an attenuations of 25 to 35 decibels on a clear dry day can be tolerated between a carrier current transmitter and receiver. When the carrier current equipments are spaced apart at maximum distance along the power line 13, minimum attenuation between each carrier current apparatus 10 and the power line 13 can be tolerated. In the usual case the attenuation then allowed between each carrier current apparatus 10 and the power line 13 is in the order of one or two decibels.

If, however, the distance along the power line 13 between the points where carrier current equipments are connected thereto are shorter than such maximum distance, more attenuation can be tolerated through the transmission line 11. Accordingly, to determine the maximum usable length of the transmission line 11 in any particular case, in view of the above considerations, the curves 40 and 41 of Fig. 5 may be utilized, where the coupling condenser 17 has a capacity of .004 microfarads.

Figs. 6, 7 and 8 are identical with Fig. 5 except that they illustrate the attenuation for various lengths of the transmission line 11 when the coupling condenser 17 has respectively capacities of 0.002 microfarad, 0.001 microfarad, and 0.00075 microfarad. In any particular case, therefore, when the voltage of the power line 13, and the attenuation between carrier current stations therealong be known, the curves in Figs. 5 through 8 may be utilized to determine the maximum usable length of the transmission line 11.

If the transmission line 11 which is to be used approaches a length equal to one quarter wave length of the carrier current wave at the operating frequency, additional consideration must be given to the possibility of tuning the apparatus 10 by means of the inductances 18 and 33. If the transmission line 11, in any particular case, is made slightly greater than one quarter wave length long, the capacity of the power line 13 and condenser 17 appears at the carrier current apparatus 10 as inductance, since a quarter wave length line acts as an impedance inversion transformer. In such a case the inductance 18 cannot be used to tune the equipment, and if it be desired to use such a transmission line, it is necessary to replace the inductance 18 with a condenser or with a capacitive combination of a condenser and an inductance. In any case, when the equipment is properly tuned by the inductance 18, or by any suitable means, the attenuation is as illustrated in the curves of Figs. 5 through 8, even though the length of transmission line 11 be exactly one quarter wave length, or a multiple thereof.

One form of the transmission line 11 which is especially suitable for connecting the carrier current apparatus 10 to the condenser 17 is a coaxial cable insulated with a rubber compound. The dielectric constant of one particular rubber compound used in practice is 3.3, so that a quarter wave length of the transmission line 11 at 150 kilocycles is 903 ft. One quarter wave length at 85 kilocycles is 1,590 ft., and one quarter wave length at 50 kilocycles is 2,710 ft. It should be remembered in making any particular installation that when the length of transmission line 11 approaches such values an inductance may be incapable of tuning the equipment at the carrier current apparatus 10.

If the exact operating frequency at which the system is to operate is not known when it is desired to determine how long the transmission line 11 may be, the determination should be made on the basis of the lowest frequency which may actually be used, since such determination generally indicates that the transmission line 11 is shorter than that which would be determined for a higher operating frequency. However, when considering whether the transmission line 11 may approach a quarter wave length or multiple thereof in length, it may be necessary to determine the actual operating frequency.

As illustrated by the curves of Figs. 5 through 8, it has been found that a transmission line 11 may be utilized to connect a carrier current apparatus 10 to a power line 13 without the necessity of providing tuning means at the connection between the transmission line and the power line, and also that an impedance matching transformer may be omitted. It is within the scope of my invention to utilize such a transmission line with tuning means only at the carrier current apparatus 10 in any type of carrier current system having a signal transmission line, of which several forms have been illustrated.

While I have shown and described a particular embodiment of my invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from my invention in its broader aspects, and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent in the United States is:

1. An arrangement for coupling carrier current apparatus to a power line spaced a substantial distance therefrom comprising, means including a transmission line extending between

said carrier current apparatus and said power line for transmitting carrier current signals therebetween, means comprising a coupling condenser and transformer for transferring signals between said power line and said transmission line and for isolating the power currents of said power line from said transmission line and matching the impedance of said transmission line to the impedance of said condenser and power line, and means for transmitting signals between said carrier current apparatus and said transmission line, the impedance of said power line measured through said condenser, transformer, and transmission line being reactive, said last mentioned means having a reactance equal and opposite in character to the reactive component of the impedance of said power line measured through said condenser and transmission line, whereby attenuation of carrier current signals transmitted between said power line and said apparatus is minimized.

2. An arrangement for coupling carrier current apparatus to a power line spaced a substantial distance therefrom comprising, means for transmitting signals between said apparatus and line comprising a transmission line, a coupling condenser and transformer connected between said transmission line and said power line, the impedance of said power line measured through said condenser and transformer being reactive whereby substantial attenuation is produced in signals transmitted through said transmission line, and means coupling said apparatus to said transmission line for tuning the impedance of said power line and coupling condenser through said transmission line, whereby said attenuation is reduced.

3. An arrangement for coupling carrier current apparatus to a power line spaced a substantial distance therefrom comprising, means for transmitting signals between said apparatus and line comprising a transmission line, and a coupling condenser and transformer connected between said transmission line and said power line, the impedance of said power line measured through said condenser being reactive, said transformer having an impedance ratio effective to match said impedance with the characteristic impedance of said transmission line, substantial attenuation being produced in signals transmitted through said transmission line in spite of said transformer because of the reactive component of said impedance, and means coupling said apparatus to said transmission line for tuning the impedance of said power line and coupling condenser through said transmission line and transformer, whereby said attenuation is reduced.

4. An arrangement for coupling carrier current apparatus including a transmitter and a receiver operative at different frequencies to a power line spaced a substantial distance therefrom comprising, a transmission line, a coupling condenser and transformer connected between said lines, said transformer having a turn ratio effective to match the impedance of said transmission line to the impedance of said power line and condenser, the impedance of said power line measured through said condenser, transformer, and transmission line being reactive at both the frequencies of said transmitter and receiver, means for connecting said transmitter to said transmission line, said connecting means having a reactance at the frequency of said transmitter equal and opposite in character to the reactance of said power line measured through said condenser, transformer, and transmission line, and means for connecting said receiver in shunt to said transmitter and at least a portion of said connecting means and for adjusting the reactance of said transmitter and said portion at the frequency of said receiver to a value equal and opposite in character to the reactance of the remainder of said connecting means, said transmission line, said coupling condenser, said transformer, and said power line at the frequency of said receiver.

5. An arrangement for coupling a first and a second carrier current apparatus, having respectively a first and a second operating frequency and each including a transmitter and a receiver, to a power line spaced a substantial distance therefrom comprising, a transmission line, a coupling condenser and transformer connected between said lines, the turn ratio of said transformer being suitable to match the impedance of said transmission line to the impedance of said power line and condenser, the impedance of said power line measured through said condenser, transformer, and transmission line having a reactive component at both said frequencies, means for connecting said first apparatus to said transmission line, said connecting means having a reactance at said first frequency equal and opposite in character to said reactive component and having high impedance at said second frequency, and means for connecting said second apparatus to said transmission line having a reactance at said second frequency equal and opposite in character to said reactive component and having high impedance at said first frequency.

EDWIN W. KENEFAKE.