Oct. 29, 1929. B. F. LEWIS 1,733,127

SIGNALING CIRCUITS

Filed June 27, 1928 3 Sheets-Sheet 1

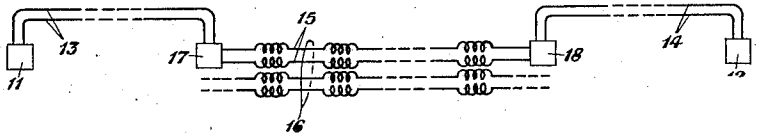


Fig. 1

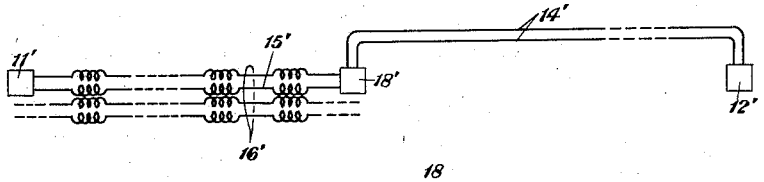


Fig. 2

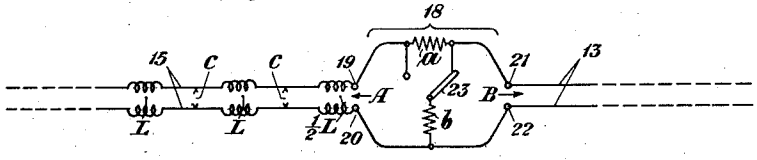


Fig. 3

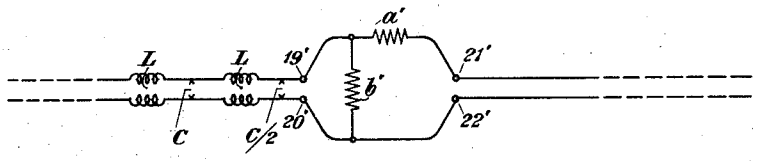


Fig. 4

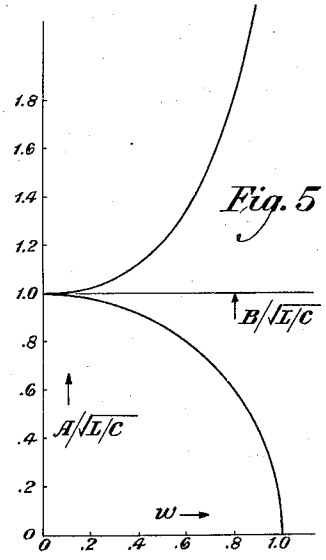


Fig. 5

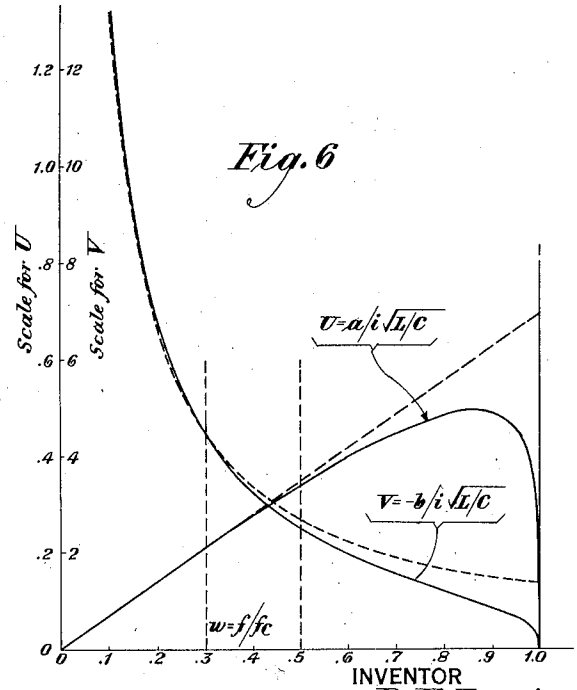


Fig. 6

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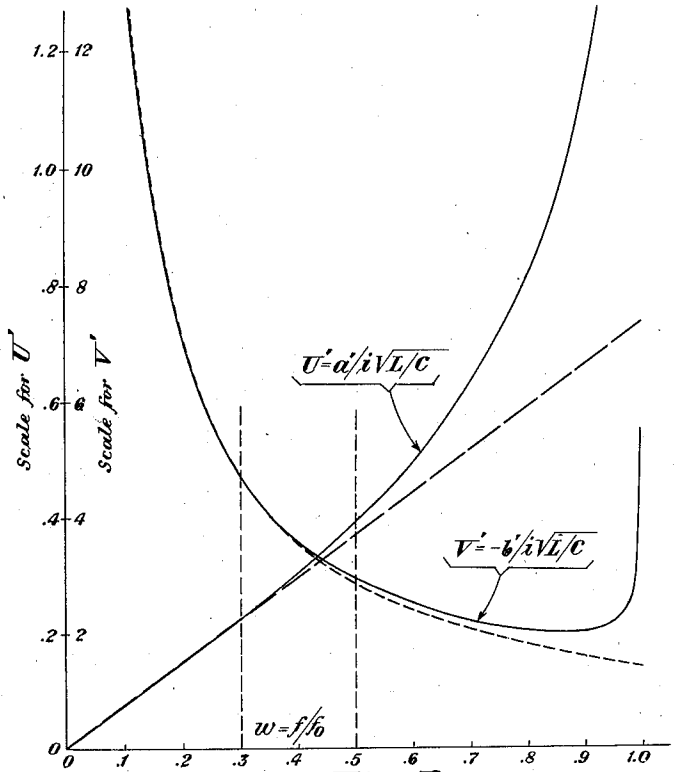


Fig. 7

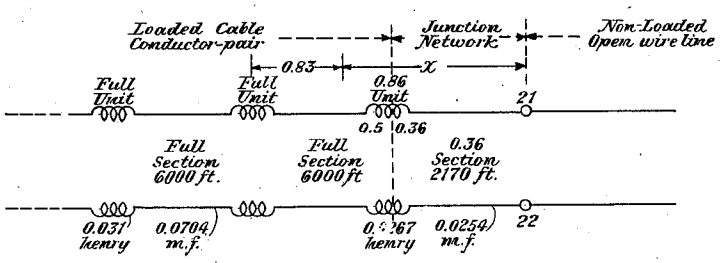


Fig. 8

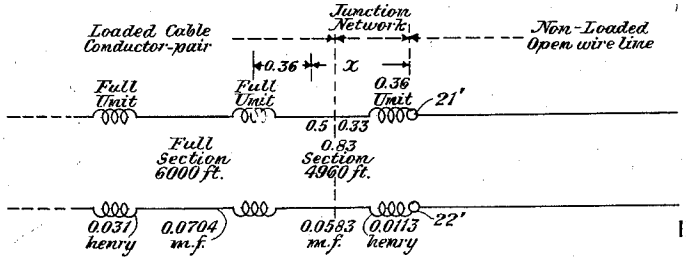


Fig. 9

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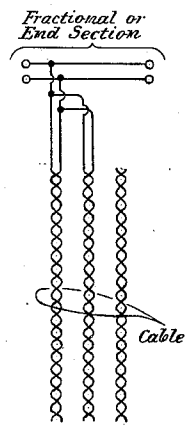


Fig. 13

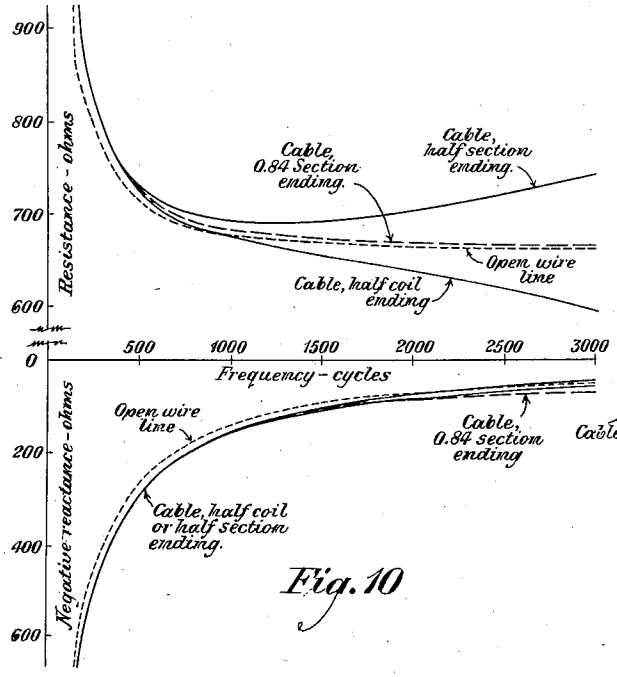


Fig. 10

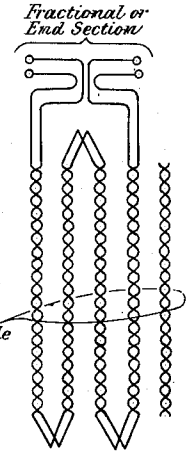


Fig. 14

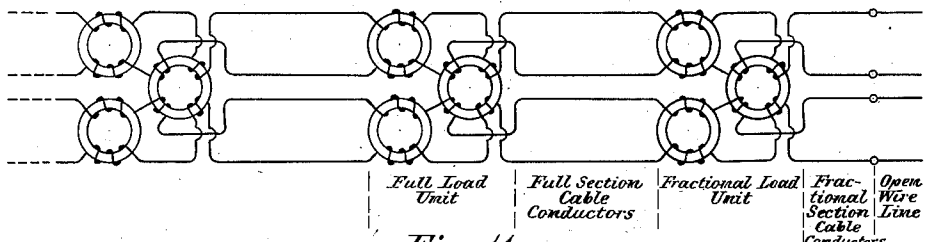


Fig. 11

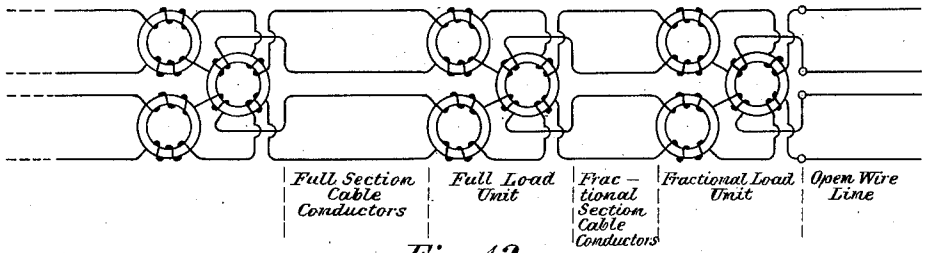


Fig. 12

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Patented Oct. 29, 1929

1,733,127

UNITED STATES PATENT OFFICE

BENJAMIN F. LEWIS, OF BROOKLYN, NEW YORK, ASSIGNOR TO AMERICAN TELEPHONE AND TELEGRAPH COMPANY, A CORPORATION OF NEW YORK

SIGNALING CIRCUITS

Application filed June 27, 1928. Serial No. 288,731.

The principal object of my invention is to provide simple and effective means for connecting in sequence two electric signal transmitting lines of different character. Another object of my invention is to provide for connecting a non-loaded open wire transmission line and a loaded cable circuit with equalization of impedance both ways at the connection over a suitable frequency range for telephone voice currents. Another object is to provide simple standardized apparatus that may be readily interposed at the junction between an open wire line and a cable to facilitate their operation as one signaling circuit. These objects and other objects of my invention will become apparent on consideration of a limited number of examples of practice according to the invention. It will be understood that the following specification relates principally to these particular examples of the invention, and that its scope will be indicated in the appended claims.

Referring to the drawings, Figures 1 and 2 are diagrams of telephone conductor systems in which my invention may be employed advantageously; Figs. 3 and 4 are detailed diagrams illustrating the principles involved in the practice of the invention; Figs. 5, 6 and 7 are curve diagrams that will be referred to in this connection; Figs. 8 and 9 are diagrams showing essential details in more specific form; Fig. 10 is an impedance-frequency diagram for a composite circuit compensated according to my invention; Figs. 11 and 12 are diagrams for quads, that is, for two side circuits and the associated phantom circuit in each figure; and Figs. 13 and 14 are diagrams suggesting how certain capacities may be embodied in the practice of my invention.

Fig. 1 represents a long distance telephone system with terminal stations at 11 and 12 and with open wire conductor pairs at 13 and 14. At an intermediate place in the line 13—14, it passes through a city or other area, where it is not practicable to carry the line in the open wire form. Accordingly, it is continued across this area in the form of a loaded line 15 comprised within a cable 16. Suitable networks are provided at 17 and 18 to facilitate the junctions between the open wire line and the loaded cable circuit at these points. In a certain aspect, my invention relates to these networks 17 and 18, examples of which will be fully disclosed in this specification.

Fig. 2 represents a long distance telephone transmission line connecting two terminal stations 11′ and 12′. The station 11′ is within a city of extended area so that the open wire line 14′ cannot be carried all the way to the station 11′. Accordingly, the open wire line 14′ is terminated at the network 18′, from which point the circuit is continued in the form of a loaded line 15′ within the cable 16′ to the terminal station 11′.

Proceeding to a discussion of the principles involved in the design of the networks such as 17, 18 or 18′, let the loaded line 15 in Fig. 3 end at its right at half coil termination so that the inductance at each coil will be L, except that for the coil at the right the inductance will be $\frac{L}{2}$. Let the impedance looking into the loaded line across its terminal points 19 and 20 be represented by A. Let the network 18 consist of a series impedance *a* and a shunt impedance *b*. A switch is shown in this figure to indicate that impedance *b* can be connected at either the right or the left of impedance *a*. For the present, and unless otherwise stated, it will be understood that the connection is at the right, as shown by the position of the switch in Fig. 3. From the right-hand terminals 21 and 22 of the network 18 extends the open wire line 13. Let the impedance looking into this open wire line from the network 18 be represented by B.

It is desired that the impedance looking into the network 18 across the terminals 19, 20 shall have the value A and that looking into this same network across the terminals 21, 22, the impedance shall have the value B. Thus will be secured the important condition that there shall be no inequality of impedances and that there shall be no reflection effects. Such irregularities, if present, will impair repeater operation on the

circuit and cause the quality of transmission to be poor.

For the open wire line 13, let the series inductance per unit length be L′, and the shunt capacity per unit length be C′. Then, as is well known, for considerable frequencies, the impedance of the open wire line is substantially a constant resistance given by the formula

$$B=\sqrt{L'/C'} \quad (1)$$

This approximation is called the "nominal impedance."

For the loaded line 15, I have already mentioned that the inductance per loading coil is L. Let the distributed capacity per section, that is, between the consecutive loads, be C where the ratio of L to C is the same as the corresponding ratio for the open wire line. The determination of L and C as a matter of design will be considered presently. Accordingly,

$$B=\sqrt{L'/C'}=\sqrt{L/C} \quad (2)$$

This makes the nominal impedance for the cable conductor the same as for the open wire line.

The impedance A of the loaded line will be sufficiently approximated by assuming that the capacity C per section is lumped. The impedance of a loaded line at full load termination, or at full section termination, or at any fractional load or section termination except half load and half section will have a reactance component. However, for a recurrent network of alternately disposed series inductances L and shunt capacities C with midcoil termination at the input, the impedance is well known to be a pure resistance, but a function of frequency, as given by the formula

$$A=\sqrt{L/C}\,\sqrt{1-w^2} \quad (3)$$

where

$$w=f/f_c \quad (4)$$

and f stands for the frequency, and f_c stands for the critical frequency, that is, the frequency at which, with increasing frequency, the loaded line cuts off and stops transmitting. The value of f_c is given by the formula

$$f_c^2=1/\pi^2 LC \quad (5)$$

Referring to Fig. 5, the lower curve shows $A/\sqrt{L/C}$ plotted against w. The horizontal line with ordinate 1.0 represents the value of $B/\sqrt{L/C}$; thus it corresponds to the nominal impedance.

The condition of impedance equality across the terminals 19, 20 is

$$A=a+bB/(b+B) \quad (6)$$

and the condition for impedance equality across the terminals 21, 22 is given by the admittance equation

$$1/B=1/b+1/(a+A) \quad (7)$$

The solution of these equations is

$$a=\sqrt{A(A-B)},\ b=AB/a \quad (8)$$

An inspection of Equations (8) shows that a and b will be both resistances or reactances according as A is greater than or less than B. Inspection of Fig. 5 shows that the last stated condition holds, that is, A is less than B, at all frequencies in the range from above $w=0$ up to $w=1.0$.

But if the switch 23 in Fig. 3 is thrown the other way, then, instead of equations (8), the solutions for a and b (call them a'' and b'' in this case) will be

$$a''=\sqrt{B(B-A)},\ b''=AB/a \quad (9)$$

Inspection of these equations shows that with A less than B (which is according to Fig. 5), a'' and b'' are resistances.

With the switch 23 to the right, a and b are reactances, but to the left, a'' and b'' are resistances; an advantage in the first alternative is that the reactances will be non-dissipative, whereas the resistances will introduce losses. Moreover, the resistances will be functions of frequency and therefore even if they can be realized physically, it will not be by means of simple resistances, but networks more or less complicated will be necessary. On the other hand, as will be shown presently, with the switch 23 to the right, the reactance values for a and b can be embodied in very simple form and with good approximation to accuracy over the necessary frequency range.

Substituting from Equations (1) to (5) for A and B in Equations (8), we obtain the following values for the network elements a and b:

$$a=\sqrt{L/C}\sqrt{1-w^2}-\sqrt{1-w^2},\ b=-a(\sqrt{1-w^2}+1)/w^2 \quad (10)$$

Referring to Fig. 6, this shows a curve U which is the plot of $a/i\sqrt{L/C}$, as given by the first of Equations (10). Also, in Fig. 6, the curve V gives $-b/i\sqrt{L/C}$ as a function of w, as expressed in the second of Equations (10); the negative sign in the foregoing expression $-b/i\sqrt{L/C}$ is for convenience so as to show the curve above the axis of abscissas in the same quadrant with the curve U.

In the design of loaded cable conductors to be connected in sequence with open wire line, the given conditions comprise the following: The inductance per unit length of the open wire line is L′, and the capacity per unit length is C′, and the resistance per unit length is R′. A conductor pair in a cable will have about the same shunt capacity per unit of length for all sizes of wire that may be open to consideration. Let this capacity per unit

length of the cable pair be C''. The next limiting condition to be considered is the distance between loads. This has become standardized for toll cables at 6,000 feet, and the same spacing will therefore be most convenient for cables to be interposed in non-loaded open wire lines transmitting only a voice frequency telephone channel. Thus the shunt capacity C per section length of the loaded line is fixed at a value dependent on C''. As already pointed out in this specification, we must have the ratio $L/C=L'/C'$, and, since C, L' and C' are fixed, this condition fixes the value of L. The time constants for the two lines should be the same, and this condition is expressed

$$R/L=R'/L' \quad (11)$$

And, since L, R' and L' are fixed, this Equation (11) fixes the resistance R of the cable pair, that is, the size of the gauge of the conductors in the cable. It remains to consider the frequency at which the cable cuts off. This is given by Equation (5), and, in practice, with L and C as they are determined by the foregoing considerations, the cut-off or critical frequency f_c is found to be about twice as high as the maximum frequency for which an impedance irregularity at the junction of the loaded cable and the open wire is important.

Hence, referring to Fig. 6, we desire to embody the reactances a and b in such form that their impedance values will plot to close to the curves U and V over the frequency range from a little above $w=0$ up to about $w=0.5$.

Knowing that inductance reactance is a linear function of frequency with zero value at zero frequency, it is at once apparent from Fig. 6 that the impedance a will be well realized by an inductance. To get a close practical approximation for the range from 0 to 0.5 for w, we take a point on curve U whose abscissa has a convenient intermediate value, say 0.3, and draw the straight, dotted line through this point and the origin. The impedance a is to be an inductance whose characteristic will be given by this dotted line. From the first of Equations (10), or from the U-curve in Fig. 6, we find that

$$a=i\sqrt{L/C}\ 0.208.$$

But we know that the impedance a will be $i2\pi f$ times the inductance where f is given by Equations (4) and (5) with $w=0.3$. Equating these two values of a, and solving for the inductance as an unknown quantity, its value is found to be 0.346L.

A glance at Fig. 6 suggests the resemblance of the curve V to a rectangular hyperbola, that is, for values of w considerably less than 1.0. Knowing that the impedance characteristic for a condenser is a rectangular hyperbola, we assume that the impedance b of Fig. 3 is embodied in a condenser and that its characteristic on Fig. 6 is to pass through the point of the curve V whose abscissa is 0.3. From the second of Equations (10), we get the value of b for $w=0.3$ and equate it to the impedance value of the assumed condenser and solve for this value as an unknown quantity. Proceeding thus, the result is obtained that the capacity value of this assumed condenser is 0.37C. The dotted line curve which intersects the curve V at the point whose abscissa is 0.3 is the impedance characteristic for this condenser.

It will be seen that the dotted, straight line characteristic for the inductance impedance a, and the dotted curve characteristic for the capacity impedance b fit approximately to the curves U and V for values of w from a little above zero up to about 0.5; as already stated, for the practical case of loaded cables connecting with non-loaded open wire lines transmitting only a voice frequency telephone channel, this is a sufficient frequency range for which an impedance irregularity at the junction of the cable and the open wire is important.

With the values that have been suggested heretofore for the open wire line and the loaded cable conductors, the inductance and capacity values for a and b are indicated in Fig. 8, which shows a loaded line on the left connected with a non-loaded open wire line on the right. Going along this composite line from left to right, we come to a full unit loading coil of inductance value 0.031 henry; then a full section of 6,000 feet of cable conductor pair of shunt capacity value 0.0704 microfarad; then another full unit load; then another full unit section; next, an inductance corresponding to the coil of value L/2 adjacent to the terminals 19, 20 in Fig. 3 combined with the inductance whose impedance value is a. According to the results heretofore obtained, the inductance of this fractional unit in Fig. 8 should be $(0.5+0.346)L$, that is, 0.846L. For practical reasons, the value of this fractional inductance unit in Fig. 8 has been fixed at the slightly different value, 0.86L, which corresponds to an inductance of 0.0267 henry. This slight discrepancy is principally due to the presence in the actual case of a certain amount of distributed inductance in the cable conductor pair and also mutual capacity in the loading coils.

The shunt impedance b is embodied in a condenser, as has already been explained. Its approximate value, according to the assumptions made heretofore, was 0.37C. For the above mentioned practical reasons, the slightly different value 0.36C has been taken. This gives, in Fig. 8, 0.36 section of cable conductor pair at the right, that is, 2,170 feet of capacity value 0.0254 microfarad. Next to the right is the non-loaded open wire line.

Thus far, dealing with Fig. 3, we have as-

sumed a mid-coil termination at 19, 20 for the loaded line. This termination makes the impedance A looking into the loaded line a pure resistance, though variable as the frequency varies. There is another termination for a loaded line that will make the impedance looking into it a pure resistance, namely, at midsection, as shown in Fig. 4, for the loaded line extending to the left from the terminal points 19′ and 20′. This midsection impedance value is shown by the upper curve in Fig. 5. By a procedure analogous to that for Fig. 3, the proper values for the impedances a' and b' of Fig. 4 may be obtained to equalize the impedances at 19′, 20′, and at 21′, 22′. When b' is at the left of a', then a' and b' will be reactances, but when at the right, they will be resistances, but not constant as the frequency varies. We reject the latter alternative on the same considerations as for our rejection of the corresponding alternative in connection with Fig. 3; and, accordingly, with the arrangement shown in Fig. 4, the following values are obtained for a' and b', namely,

$$a'=1/b,\ b'=1/a \quad (12)$$

The characteristic curves for the impedances a' and b' of Fig. 4, as functions of the frequency ratio w, are shown in Fig. 7, for which the meaning will be readily apparent in view of the analogy to Fig. 6 and the explanation that that has been given for Fig. 6. In the same way as for Fig. 6, we assume an inductance for a' and a capacity for b' such that their impedance values will give points on the curves U′ and V′, respectively, at the frequency value for which $w=0.3$. The dotted lines in Fig. 7 show the impedance characteristics for such assumed inductance and capacity, and show a satisfactory agreement with the solid line characteristics U′ and V′ within the frequency range from a little above zero to about $w=0.5$.

In Fig. 9, the specific values for the junction network elements are indicated for the particular example of open wire line and loaded line heretofore mentioned. Going along the loaded line from left to right, we come to the last full unit loading coil and then a section which, according to the theory heretofore developed, should have the capacity value $(0.5+0.346)C$. For practical reasons, as explained previously, this is taken at a slightly different value, namely, 0.83C, or, 4,960 feet with shunt capacity value 0.0583 microfarad. Next, on the right, is the fractional coil to embody the series impedance a' of Fig. 4. This would be 0.37L according to the assumptions made, but, for practical reasons as mentioned above, it is taken at the slightly different value of 0.36L, giving the coil at the right in Fig. 9 an inductance value 0.0113 henry. Next, to the right, comes the non-loaded open wire line.

I desire to call attention to the flexibility of design afforded by my system of joining an open wire line and a loaded line. Evidently, it will often be impracticable to make the initial section length of loaded line, at the junction, of the full normal value, or any single definite fraction thereof. If the distance from the end of the non-loaded open wire line to the first loading station is less than 0.36 section or greater than 0.83 section, then the system of Fig. 8 will be preferable to that of Fig. 9. Attention is directed to the stretch designated x in Fig. 8. In geographical extent the loaded line may end at any point along this stretch x, the remainder of the conductor pair between such point and the point 21, 22 being made up of local capacity. For such local capacity, stub cable may be employed as will be explained presently.

On the other hand, if the distance from the end of the non-loaded open wire line to the next loading station is greater than 0.36 section but less than 0.83 section, then the system of Fig. 9 will be preferable. In this case, the line may end in geographical extent at any point within the stretch x, the remainder of the conductor pair from such point to the point 21′, 22′ being made up of local capacity.

It will be noticed that in Figs. 8 and 9 the non-loaded open wire line coming in from the right ends at a definite point; but the loaded line coming in from the left merges at a geographically indefinite point into the junction network. In other words, the geographical extent of the line as a whole may lie more or less in the junction network on its side toward the normally loaded line.

Fig. 10 shows certain actual resistance and reactance components for the lower range of frequencies, that is from a little above zero up to 3,000 cycles per second. The characteristics in Fig. 5 are based on the assumption of zero ohmic resistance; this assumption gives closely approximate results for the resistance component of the impedance at higher frequencies, but it does not do so at lower frequencies. Moreover, the assumption just mentioned implies absence of a reactance component, but without the assumption there will be an actual reactance component of small value at higher frequencies and of greater value at lower frequencies. All these statements will be apparent in connection with Fig. 10, and the legends thereon, and moreover it will be seen that the loaded line with fractional section ending as in Fig. 8 matches the open wire line to a close approximation, both as to resistance and reactance, over the whole range below 3,000 cycles. This practical case, here used for illustration, deals with a 104-mil non-loaded non-pole pair open wire side circuit and a 19 gauge cable side circuit. A large part of the slight discrepancy between the characteristics for the open wire

line and the 0.84 section cable pair is due partly to a small design compromise to adapt the cable system to certain other cases of open wire lines, and partly to the fact that the ideal size of cable conductor to go with the given open wire line is different from the nearest available standardized size which is taken instead of such ideal size.

The principles of my invention may be employed advantageously not only for the side circuits of a quad, but also for the associated phantom circuit. The full section lengths will be the same for the phantom circuit as for the side circuits, and the fractional section length will be the same for the phantom circuit as for the side circuits. As is well understood, the phantom load coils will each have four windings instead of two, as for the side load coils, and since the capacity per section for the phantom circuit is different from the capacity per section for each side circuit, the inductance value of each normal phantom load coil will be different from the corresponding value for each side circuit load coil. But the inductance value of a phantom fractional load coil will have the same ratio to the inductance value of a fractional side circuit load coil that a full phantom coil has to a full side coil.

Fig. 11 shows the quad with the junction arranged on the base of midcoil ending for the loaded lines, and Fig. 12 shows the quad with the junction arranged on the base of a midsection ending for the loaded lines. With the legends inscribed on these figures, it is thought that their significance will be readily apparent without further explanation. One noteworthy advantage of my invention is that the relatively simple design for each side circuit makes it easy to combine the sides in a phantom.

As already suggested, the distance from the terminals of the open wire line to the first loading station away therefrom will be different in different cases, but always less than 6,000 feet according to the specific example here presented. Accordingly, in many cases, more or less building out of section length will be necessary and, for this purpose, a moderate length of cable in proximity to the open wire line terminals may be employed. The necessary building out capacity may be obtained by utilizing several stub conductor pairs in parallel, with their distant ends open, as indicated diagrammatically in Fig. 13. Or, a sufficient number of conductor pairs in the local cable section may be interposed in series in the line, as indicated in Fig. 14. One advantage of Fig. 14 over Fig. 13 will be the simulation with respect to resistance as well as capacity.

Referring to Figs. 8 and 9 it will be seen that the only necessary equipment to enable the linemen to connect open wire lines and cables consists of short lengths of cable to be utilized as explained in connection with Figs. 13 and 14, and two sets of inductance coils of values respectively 0.86L and 0.36L where L is the inductance value of the normal coil on the loaded line.

The fractional values herein disclosed for the junction coils and sections are approximations which may be conveniently expressed as five sixths and one third, that is the fractional coil in Fig. 8 and the fractional section in Fig. 9 are each of about five sixths the normal values for respective coil and section on the loaded line, and similarly the fractional section in Fig. 8 and the fractional coil in Fig. 9 are each of about one third the normal values on the loaded line.

I claim:

1. In combination, in tandem, a smooth line and a lumped loaded line, the loaded line consisting of alternately recurrent elements of two kinds, namely, coils and conductor sections, each coil beyond the coil nearest to the smooth line having a certain normal inductance value, and each conductor section beyond the section nearest to the smooth line having a certain normal shunt capacity value, the element nearest the smooth line having a value about one-third of the normal value for that kind of element, and the element next nearest the smooth line having a value about five-sixths the normal value for that kind of element.

2. In combination, in tandem, a smooth line and a lumped loaded line, the loaded line consisting of alternately recurrent elements of two kinds, namely, coils and conductor sections, each coil beyond the coil nearest to the smooth line having a certain normal inductance value, and each conductor section beyond the section nearest to the smooth line having a certain normal shunt capacity value, the element nearest the smooth line having a value about one-third of the normal value for that kind of element, and the element next nearest the smooth line having a value about five-sixths the normal value for that kind of element, the ratio of said normal inductance value to said normal shunt capacity value being the same as the ratio of the series inductance per unit length to the shunt capacity per unit length for the smooth line.

3. A transmission line comprising, in sequence along its length, alternate coils of normal inductance value L and conductor sections of normal shunt capacity value C, next in sequence an element of one of these two kinds and of about five-sixths normal value for that kind of element, next in sequence an element of the other kind of about one-third the normal value for that kind of element, and next in sequence a smooth line with the ratio of its series inductance to its shunt capacity per unit length equal to L/C.

4. A transmission line comprising, in se-

quence along its length, alternate coils of normal inductance value L and conductor sections of normal shunt capacity value C, next in sequence an element of one of these two kinds and of about five-sixths normal value for that kind of element, next in sequence an element of the other kind of about one-third the normal value for that kind of element, and next in sequence a smooth line with the ratio of its series inductance to its shunt capacity per unit length equal to L/C, the ratio of resistance to inductance for a unit length of the smooth line being equal to the corresponding ratio for a full section length comprising one normal coil of the loaded line.

5. A set of unit elements for the construction and connection of loaded lines and open wire lines, comprising an open wire line, full section lengths of cable conductor pairs, additional cable conductor pairs adjustable to fractional length, full value inductance coils and additional inductance coils of two values, one substantially 0.86 of said full value and the other substantially 0.36 of said full value.

6. In combination, in tandem, a smooth line and a dumped loaded line, the loaded line consisting of alternately recurrent elements of two kinds, namely, coils and conductor sections, each coil beyond the coil nearest to the smooth line having a certain normal inductance value, and each conductor section beyond the section nearest to the smooth line having a certain normal shunt capacity value, the two elements nearest the smooth line having adjusted fractional values to equalize the impedance both ways along the composite line over the lower half of the frequency range of the loaded line.

In testimony whereof, I have signed my name to this specification this 21st day of June, 1928.

BENJAMIN F. LEWIS.