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REDUCTION OF ATTENUATION DUE TO THE CONDUCTANCE
LOSSES IN CROSS ARMS AND INSULATOR PINS
Original Filed July 1, 1925

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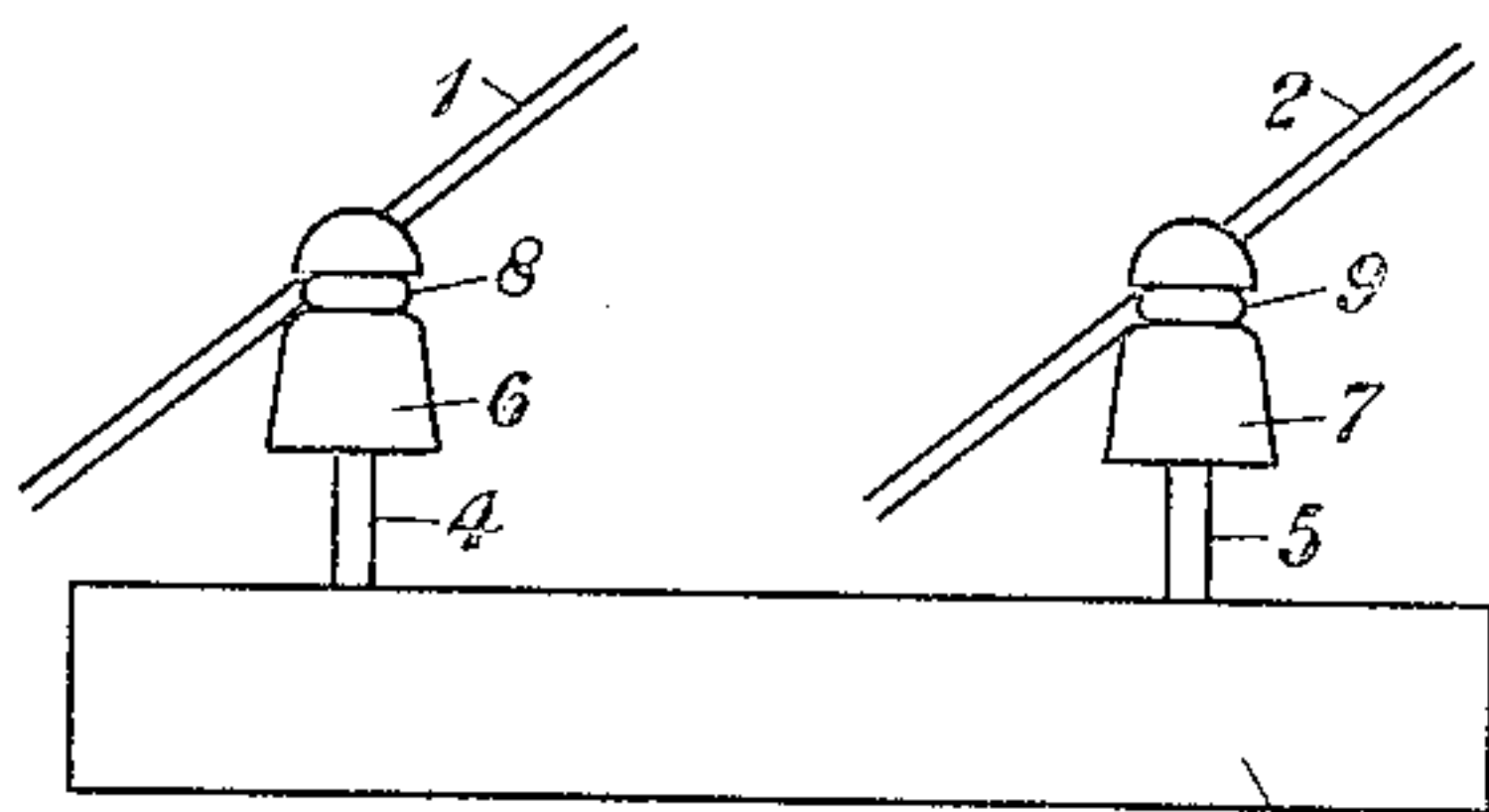


Fig. 1

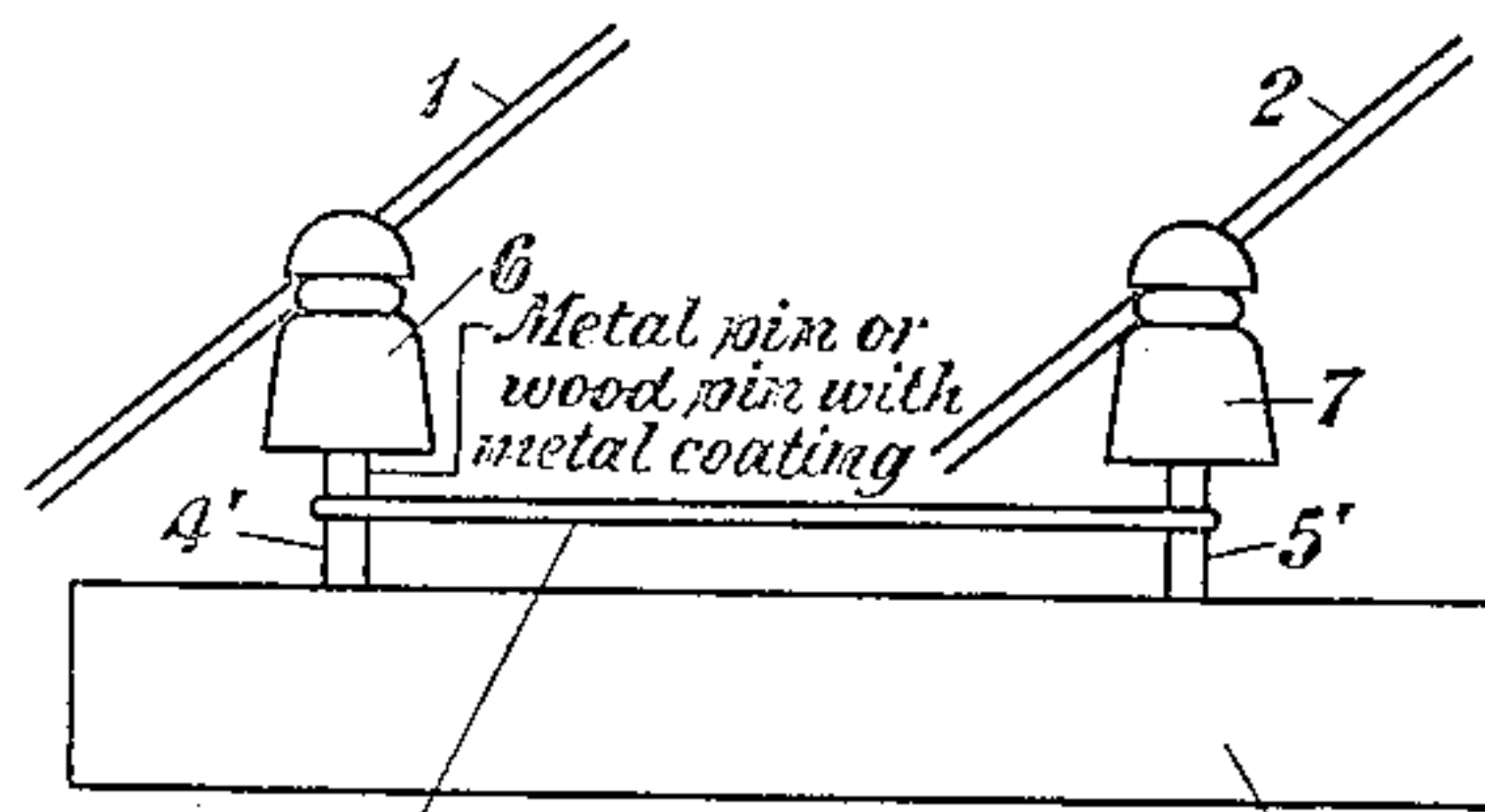


Fig. 3

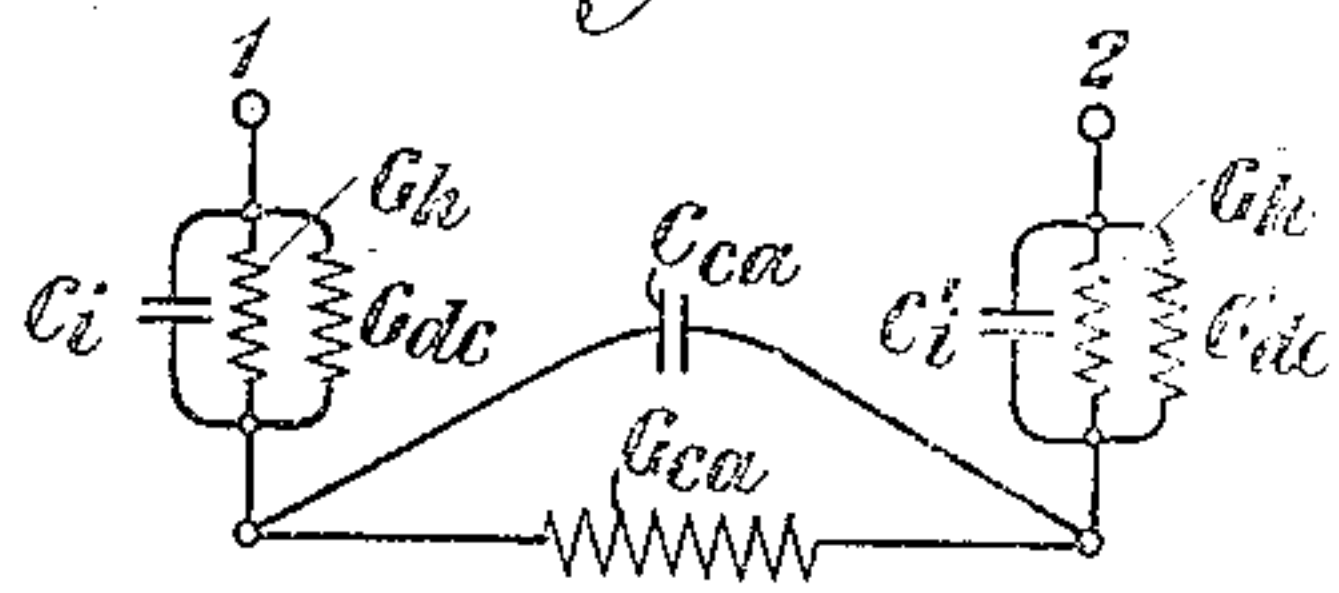


Fig. 2

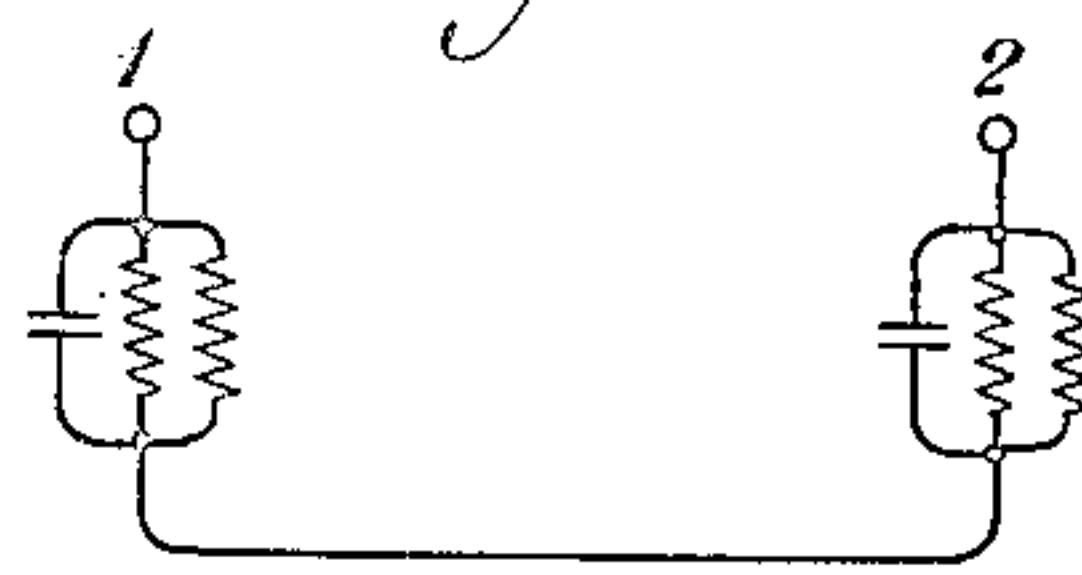


Fig. 4

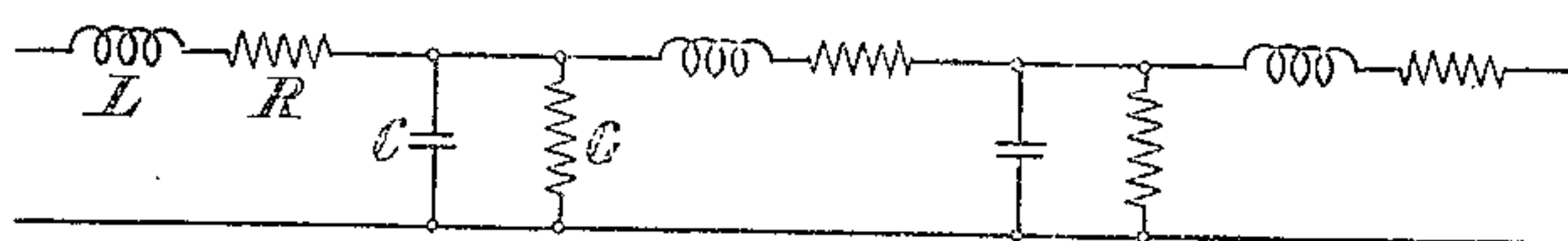


Fig. 5

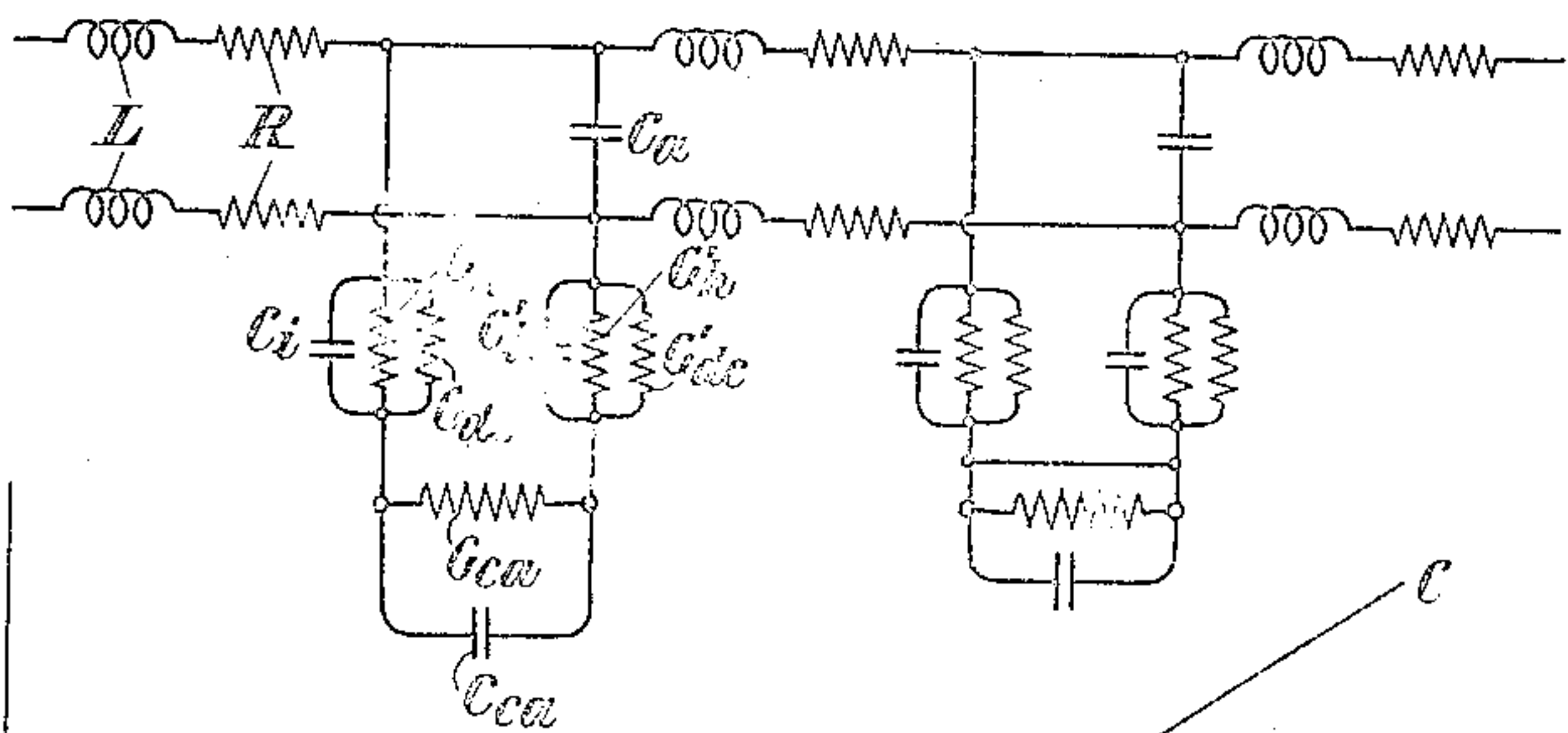


Fig. 6

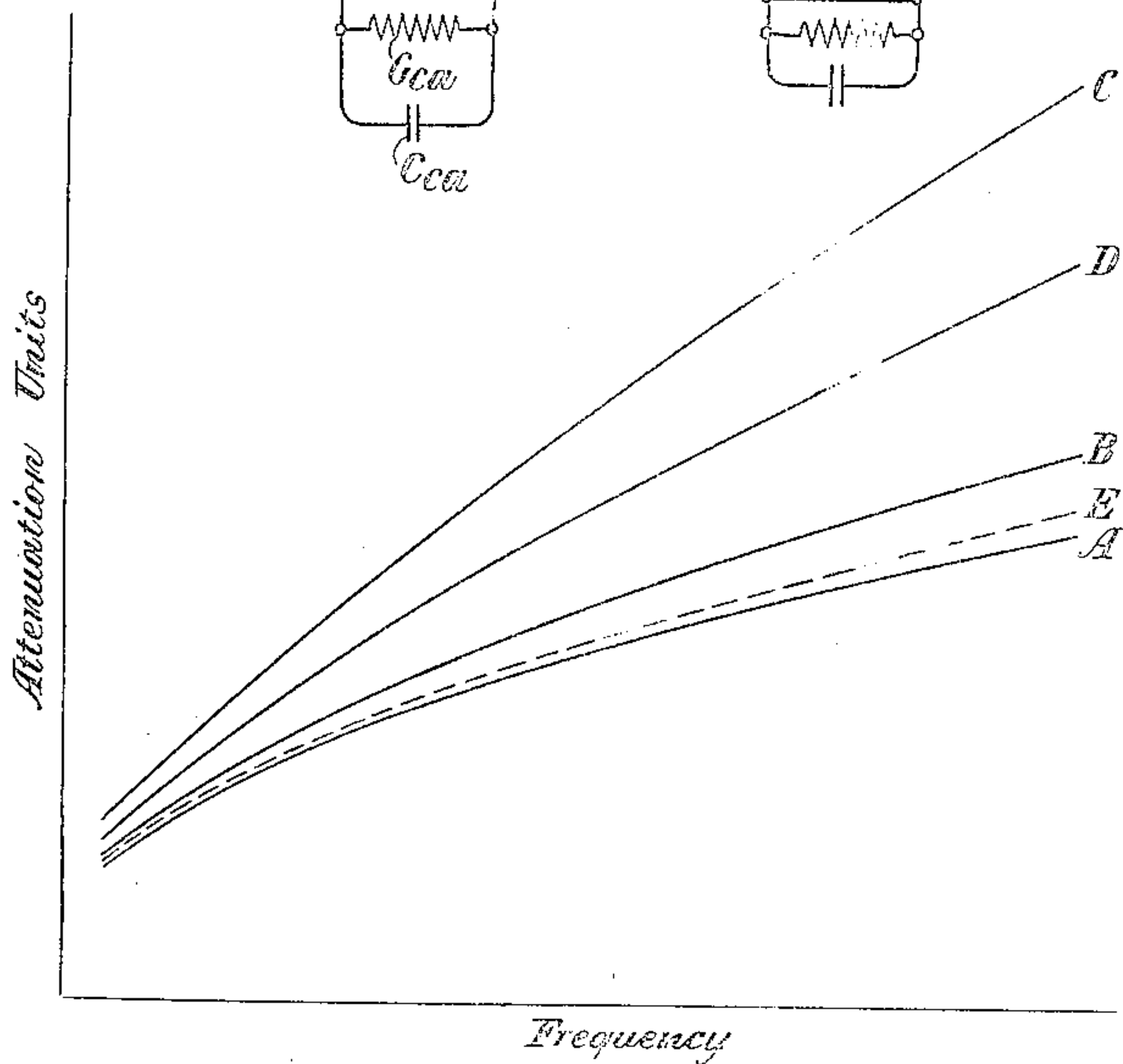


Fig. 7

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UNITED STATES PATENT OFFICE.

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REDUCTION OF ATTENUATION DUE TO THE CONDUCTANCE LOSSES IN CROSS ARMS AND INSULATOR PINS.

Application filed July 1, 1925, Serial No. 40,916. Renewed September 1, 1928.

This invention relates to transmission circuits, and more particularly to means for and methods of reducing the transmission loss in such circuits.

5 With the development of methods of transmitting telephonic and telegraphic signals by means of carrier currents propagated along open wire lines, new transmission problems have been introduced. Owing to the
10 fact that the carrier currents employed are relatively high in frequency as compared with the voice currents or Morse currents utilized in the ordinary methods of communication, it has been found that the at-
15 tenuation is very markedly increased, so much so, in fact, that repeaters for amplifying the transmitted currents must be separated by much shorter distances, thereby adding to the expense of the plant outside
20 the terminal stations at which the carrier apparatus is applied. Furthermore, the attenuation is so great that it has been impracticable to employ on telephone lines carrier frequencies much above 30,000 cycles per
25 second.

An analysis of the factors producing this attenuation shows that there are three principal factors entering into it,—first, the
30 A. C. resistance of the line conductors themselves, which increases with frequency because of skin effect; second, a leakage loss in the insulators employed; and, third, an additional leakage loss in the cross-arms and pins carrying the insulators.

35 At present there are no practical methods of eliminating the losses due to the first of these factors, as this loss appears to be inherent in the conductor itself as now constructed. The losses due to the second of
40 these factors, sometimes referred to as the hysteresis loss of the material of the insulator, may be to a large extent overcome by certain methods of insulator construction which are particularly set forth and claimed in an ap-
45 plication filed of even date herewith in the names of H. A. Affel and E. I. Green, said application being entitled "Reduction of attenuation due to leakage losses between con-
50 ductors." The present invention is concerned with a means for and a method of overcoming the losses occurring in the cross-arms and the insulator pins.

The invention may now be more fully understood from the following description when

read in connection with the accompanying 55 drawing, in which Figure 1 illustrates the normal arrangement of the cross-arms and insulator pins of a transmission line; Fig. 2 is an equivalent electrical circuit for the arrangement of Fig. 1; Fig. 3 illustrates the
60 improved method of construction of the cross-arms and insulator pins in accordance with the present invention; Fig. 4 is an equivalent electrical circuit for the arrangement of Fig. 3; Figs. 5 and 6 are theoretical
65 circuits illustrating the factors that enter into the propagation of alternating currents along transmission lines; and Fig. 7 is a series of curves illustrating the advantages de-
70 rived by the use of the present invention.

Referring to Fig. 1, which illustrates in simplified form a typical cross-arm arrangement such as is employed in connection with
75 telephone lines, 1 and 2 designate a pair of conductors of a telephone line such as are commonly strung from pole to pole across the country in ordinary open-wire construction. The cross-arm 3 is usually a wooden
80 bar having wooden pins 4 and 5 upon which are mounted insulators 6 and 7, usually of glass or other non-conductive material. The conductors 1 and 2 are secured to the insulators 6 and 7 by means of tie wires or con-
85 ductors 8 and 9.

In order to understand how the losses arise 85 from leakage through such a system as that above described, it must be remembered that the wood comprising the cross-arm 3 and the pins 4 and 5 is not a perfect non-conductor, but is in fact a relatively poor dielectric as
90 compared with the glass of which the insulators 6 and 7 are composed. The cross-arm and the pins therefore act as a condenser with a shunt leakage path of high resistance. Furthermore, the metal of the conductors 1
95 and 2 adjacent the insulators and the metal of the tie wires 8 and 9 constitute a plate of a condenser of which the glass insulator itself is the dielectric and of which the wooden
100 pin is the other plate. During wet weather conditions the outer plate of the condenser is, in effect, considerably enlarged in area due to the wetting of the outer surface of the glass of the insulator, so that the leakage
105 effects produced by the insulator are greatly augmented in wet weather.

The action of the insulator and its associated parts as a condenser involves three

factors,—first, the capacity C_i between its plates (that is, the capacity between the line conductor, tie wire, and moisture, if any, on its outer surface, on the one hand, and the insulator pin, on the other hand); second, the conductors G_{dc} representing the direct current leakage from the line conductor over the outer surface of the insulator and under its petticoat to the supporting pin. This direct current leakage does not vary with frequency, and, being a surface leakage, is, of course, worse in wet weather than in dry weather, but in general represents a rather small element of the total transmission loss; third, the conductance G_h which represents the dielectric hysteresis losses in the material of the insulator itself. This conductance is a function of the capacity of the insulator and increases with the frequency, so that at high frequencies it becomes a very material factor.

These elements entering into the action of the insulator are illustrated in diagrammatic form in Fig. 2. Over and above these factors there are two other factors with which the present invention is primarily concerned, namely, the equivalent capacity C_{ca} of the cross-arm and pins, and the equivalent conductance G_{ca} , representing the sum of the true conductance between the inner surface of one insulator and that of the other, and an additional conductance representing the dielectric losses in the cross-arm and pins. These factors are also represented schematically in Fig. 2. In order to eliminate the equivalent conductance of the pins and the cross-arm, the pins are either made of conductive metal, as shown at 4' and 5' in Fig. 3, or, where wood is used, the wood is sheathed by a metallic conductor such as a metallic foil wrapped about the pin or by a thin metal jacket of copper or other suitable material. In addition, the metallic pins in the one case or the metallic sheaths in the other case are directly connected by a metallic conductor 10 of Fig. 3, said conductor being of substantially zero resistance, so that practically a dead short-circuit connection exists between the inner surface of the insulator 6 and the inner surface of the insulator 7. The resultant equivalent electrical circuit is illustrated diagrammatically in Fig. 4.

The present invention thus far in the description has been limited to a circuit of a single pair of wires. It is obviously applicable to circuits consisting of several wires. For example, the common phantom circuit employs two wires in each side of the circuit. For such a circuit the metallic pins in one case or the metallic sheaths in the other case are all joined by a metallic conductor so that a substantially short-circuit condition exists between the inner surface of all insulators of the one side of the circuit and the inner surface of all insulators of the other side.

In order to understand how this construc-

tion results in reducing the leakage loss, involving, as it does, an arrangement which at first thought would seem to provide a better leakage path than the original construction, a brief discussion of the theory of transmission will now be considered. Referring to Fig. 5, any transmission system of the usual type herein discussed may be thought of as a line made up of a large number of sections, each section comprising series inductance L , due to the material of the line wires themselves, series resistance R , which is also inherent in the material of the line wires themselves, a shunt capacity C , and a shunt conductance G . The propagation constant of such a conductive system may be expressed by the well-known formula:

$$y = \sqrt{(R + jL\omega)(G + jC\omega)} = \alpha + j\beta$$

in which y is the propagation constant per unit length, and R , L , G and C are, respectively, the resistance, inductance, conductance, and capacity per unit length. ω is 2π times the frequency; j is the operator $\sqrt{-1}$; α is the attenuation constant per unit length, and β is a term representing a mere change in the phase of the current transmitted. Now the value of α in the above equation is given by the expression:

$$\alpha = \sqrt{\frac{1}{2} \sqrt{(R^2 + L^2\omega^2)(G^2 + C^2\omega^2)} + \frac{RG - LC\omega^2}{2}}$$

When $L^2\omega^2$ is large compared to R^2 , and $C^2\omega^2$ is large compared with G^2 , which is the case for the frequencies employed for carrier transmission, this expression reduces to:

$$\alpha \div R/2\sqrt{C/L} + G/2\sqrt{L/C}$$

It therefore follows that any reduction of either the resistance R or the conductance G will result in a decrease in the attenuation of the circuit.

As has already been stated, the resistance R , being an inherent characteristic of the line conductors themselves, cannot be eliminated by any practical physical means. It is, however, possible to effect a very large reduction in the conductance G .

In order to apply the theoretical considerations just disclosed to the practical problem presented in the case of open wire lines carried upon poles, let us refer to the diagram of Fig. 6, which shows the electrical equivalent of an open wire line whose conductors are mounted upon glass insulators which are in turn mounted upon pins carried by cross-arms. The capacity C of Fig. 5 is now represented by the capacity C_a due to the air acting as a dielectric between the line conductors, and the capacities C_i and C_i' which correspond to the capacities due to the action of an insulator as a condenser, as already described. The action of the air as a dielectric involves no leakage loss, or, at

any rate, the leakage loss is so small that it may be neglected. The capacities C_1 and C_1' , however, have associated with them dielectric losses represented by the conductances G_h and G_h' . Likewise the conductances G_{dc} and G_{dc}' are associated with these capacities, but these conductances represent direct current leakage only and are of relatively small value. As already explained, however, all of the conductances associated with the capacities C_1 and C_1' may be very greatly reduced by suitable methods of insulator construction. There remains, however, the conductance G_{ca} which represents the losses in the wooden insulator pins and the cross-arm. If this conductance is short-circuited, and thereby eliminated from the circuit, the conductance G of Fig. 5 is proportionately reduced, and, as will be apparent from the equations above given, this reduction in the value of G results in a decrease of the energy loss.

A demonstration of this fact may be given as follows: Assume for the moment that the conductances associated with the insulators are zero, a condition which, as already noted, can be approximated in practice. For this condition it is clear that the current flowing through the conductance G_{ca} will produce an energy loss which, of course, must be subtracted from the energy transmitted along the circuit. If this conductance is short-circuited, however, the current flowing between wires is a pure capacity current which produces no loss. In this connection it may be noted that the result which applicant attains by short-circuiting the pins and cross-arm could theoretically be obtained by making their equivalent conductance zero, but it is impossible to realize this condition in practice.

An idea of the magnitude of the reduction in leakage loss thus effected may be obtained from consideration of the curves of Fig. 7. These curves represent the attenuation at different frequencies of a transmission line, each of the curves representing a different condition of the circuit. The curve A, for example, represents the variation of attenuation with frequency where the transmission line involves series resistance R (the skin effect), series inductance L , and shunt capacity C , but no leakage conductance G . It will be observed that the attenuation increases as the frequency becomes higher, and this is due to the fact that the series resistance R is involved. If there were no series resistance, the attenuation would be uniform at all frequencies.

Curve B represents the variation in attenuation with frequency, as observed in an actual transmission line under dry weather conditions. Here, of course, we have leakage conductance G due to the hysteresis loss in the insulators and due to the leakage through

the cross-arms and pins. Curve C is a similar curve for the same circuit under wet weather conditions. It will be observed that the attenuation has now been enormously increased, due primarily to the wetting of the surface of the insulators, thereby increasing the capacity with a consequent increase of the dielectric losses represented by G_h and G_h' of Fig. 6.

Unfortunately the plant must be engineered for the wet weather condition when the attenuation is enormously increased. Not only must the circuit be so arranged that the transmission will be commercial under this condition, but special arrangements must be provided for maintaining the transmission constant under all weather conditions. It becomes obvious, therefore, that if the enormous loss represented by the curve C can be eliminated or even substantially eliminated so that we have a condition approaching the curve A, an immense saving in the plant will be effected not only by reason of the reduction in the number of repeaters necessary, but also by reason of the fact that transmission regulators for maintaining the transmission constant under different weather conditions will not be necessary.

The curve D represents the variation of the attenuation with frequency under wet weather conditions where the pins and cross-arms have been short-circuited in accordance with the present invention. It will be observed that the transmission loss due to the conductance G of Fig. 5 has been reduced to almost half its original value. The variation of the loss in pins and cross-arms due to changing weather conditions has likewise been eliminated.

By suitable methods of insulator construction described and claimed in the co-pending application of Messrs. Affel and Green, already referred to, the transmission loss represented by the curve D may be reduced even in wet weather conditions to the dotted line curve E. It will be noted that the use of applicant's invention, together with the improved methods of insulator construction, reduces the transmission loss to practically the same proportions as would exist if there were no leakage conductance whatever and there were no other attenuation involved than that produced by the skin resistance R of the line conductors. The transmission loss in wet and dry weather conditions would not materially vary, so that arrangements for maintaining the transmission constant would no longer be necessary. Furthermore, the absolute reduction in attenuation represented by the curves C and E would enable the use of a proportionately lesser number of repeaters.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing

from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a transmission circuit involving a pair of metallic conductors carried by insulators mounted upon wooden pins carried by wooden cross-arms and arranged so that one conductor acts as a return for the other, the method of reducing leakage losses which consists in short-circuiting the conductance of the insulator pins and cross-arms between the inner wall of the insulators of one wire of a pair and the inner wall of the insulators of the return wire of the pair.
2. A transmission circuit comprising a pair of metallic conductors strung along a pole line and arranged so that one conductor acts as a return for the other, cross-arms carrying insulators mounted upon pins, the line conductors being connected to the insulators, and a non-magnetic conductor of substantially zero resistance extending from the surface of each insulator of one line of the pair to the surface of the corresponding insulator of the return wire of the pair.
3. A transmission circuit comprising a pair of metallic conductors strung along a pole line and arranged so that one conductor acts as a return for the other, cross-arms carrying insulators mounted upon pins, the line conductors being connected to the insulators, and a conductor of non-magnetic material for short-circuiting the conductance of each cross-arm and its insulator pins between the inner wall of the insulators of one wire of a pair and the inner wall of the insulators of the return wire of the pair.
4. A transmission circuit comprising a pair of metallic conductors strung along a pole line and arranged so that one conductor acts as a return for the other, cross-arms carrying insulators mounted upon pins, the line conductors being connected to the insulators, and a non-magnetic conductor of substantially zero resistance connected from the surface of each insulator of one wire of the pair to the surface of the corresponding insulator of the return wire of the pair in parallel with the conductance of the cross-arm and insulator pins.
5. A transmission circuit comprising a pair of metallic conductors strung along a pole line and arranged so that one conductor acts as a return for the other, cross-arms carrying insulators mounted upon pins, the line conductors being connected to the insulators, said insulator pins having a conductive surface, and a low resistance conductor of non-

magnetic material extending from the surface of each insulator pin of the conductor of the pair to the surface of the corresponding pin of the return wire of the pair.

6. A transmission circuit comprising a pair of metallic conductors strung along a pole line and arranged so that one conductor acts as a return for the other, cross-arms carrying insulators mounted upon pins, the line conductors being connected to the insulators, the insulator pins being constructed of metallic conductors, and a low resistance conductor of non-magnetic material being bridged from each insulator pin of one conductor of the pair to the corresponding pin of the return conductor of the pair.

7. In a transmission circuit, a pair of metallic line conductors stretched along a pole line and arranged so that one conductor acts as a return for the other, pairs of insulators upon which the line conductors are mounted at each pole, and a supporting means for each pair of insulators, said supporting means being of non-magnetic material and providing a conductive path of practically zero resistance extending from the inner surface of each insulator of one wire of the pair to the inner surface of the corresponding insulator of the return wire of the pair.

8. In a transmission circuit involving a pair of metallic conductors carried by insulators mounted upon pins carried by wooden cross-arms and arranged so that one conductor acts as a return for the other, the method of reducing leakage losses which consists in short-circuiting the conductance of the cross-arms between the inner walls of the insulators of one wire of a pair and the inner walls of the insulators of the return wire of the pair.

9. A transmission circuit comprising a pair of metallic conductors strung along a pole line and arranged so that one conductor acts as a return for the other, wooden cross-arms carrying insulators mounted upon pins, the line conductors being connected to the insulators, means for reducing leakage losses, comprising short-circuiting connections of conductive material extending between the inner walls of the insulators of one wire of a pair and the inner walls of the insulators of the return wire of the pair for short-circuiting the conductance of the cross-arms.

In testimony whereof, I have signed my name to this specification this 30th day of June, 1925.

LEON T. WILSON.