REDUCTION OF LOSSES IN INSULATORS, PINS, AND CROSS ARMS

Filed July 1, 1925 2 Sheets-Sheet 1

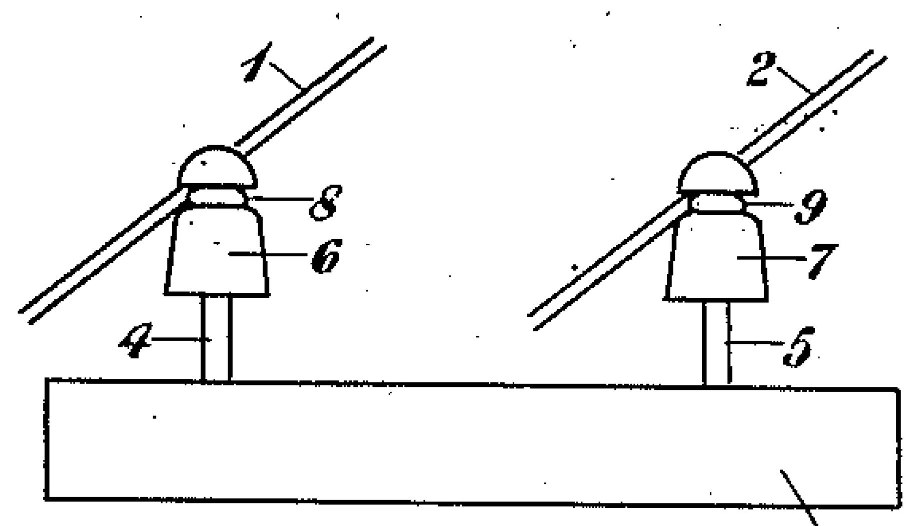

Fig. 1

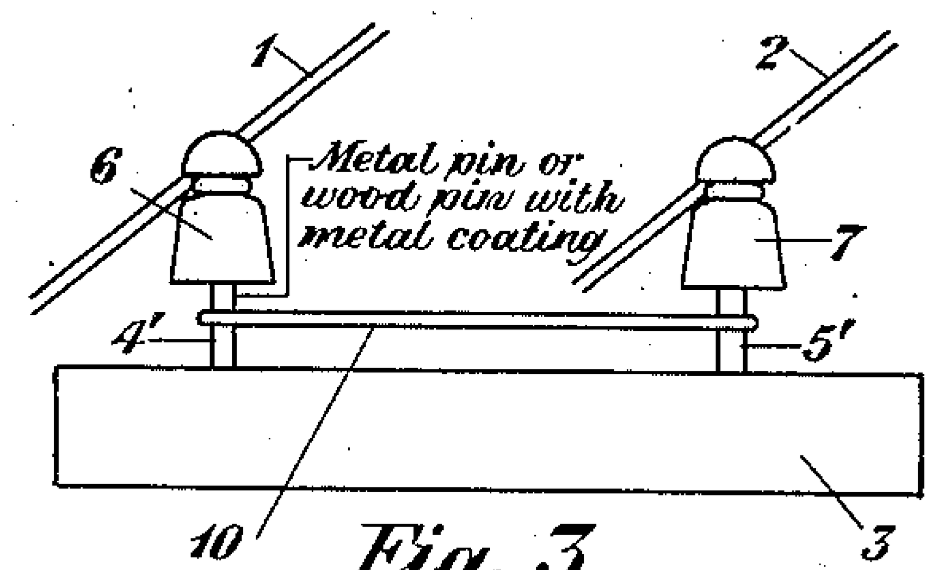

Fig. 3

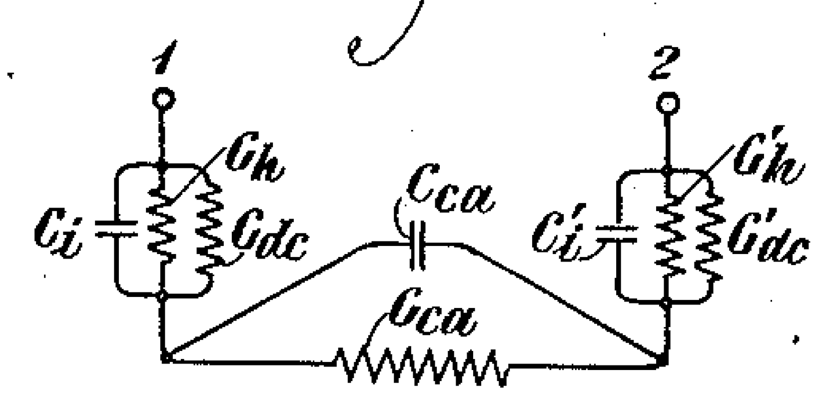

Fig. 2

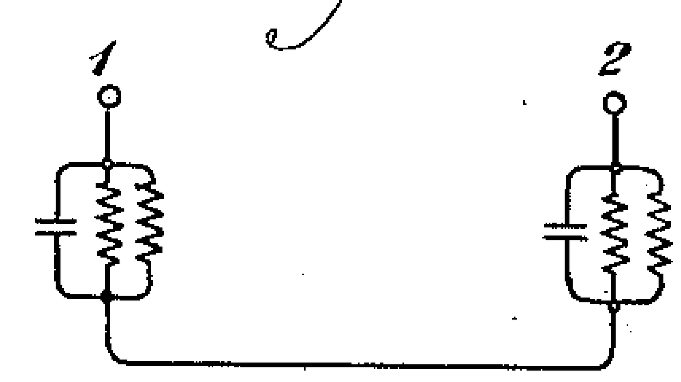

Fig. 4

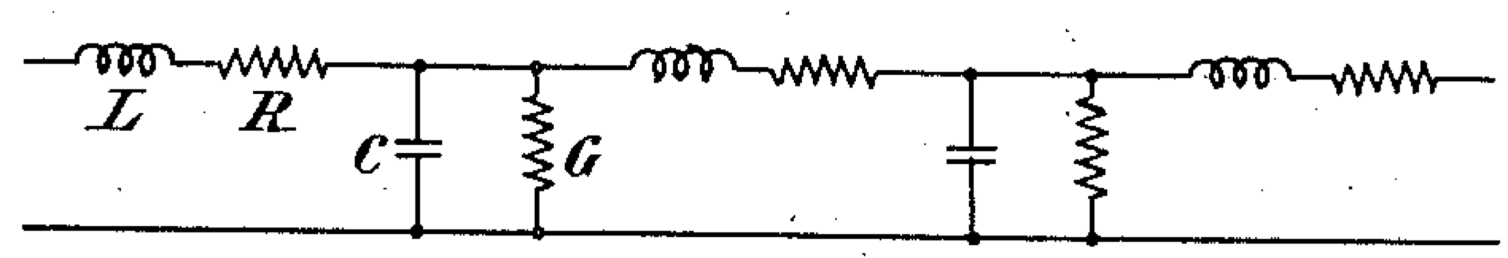

Fig. 5

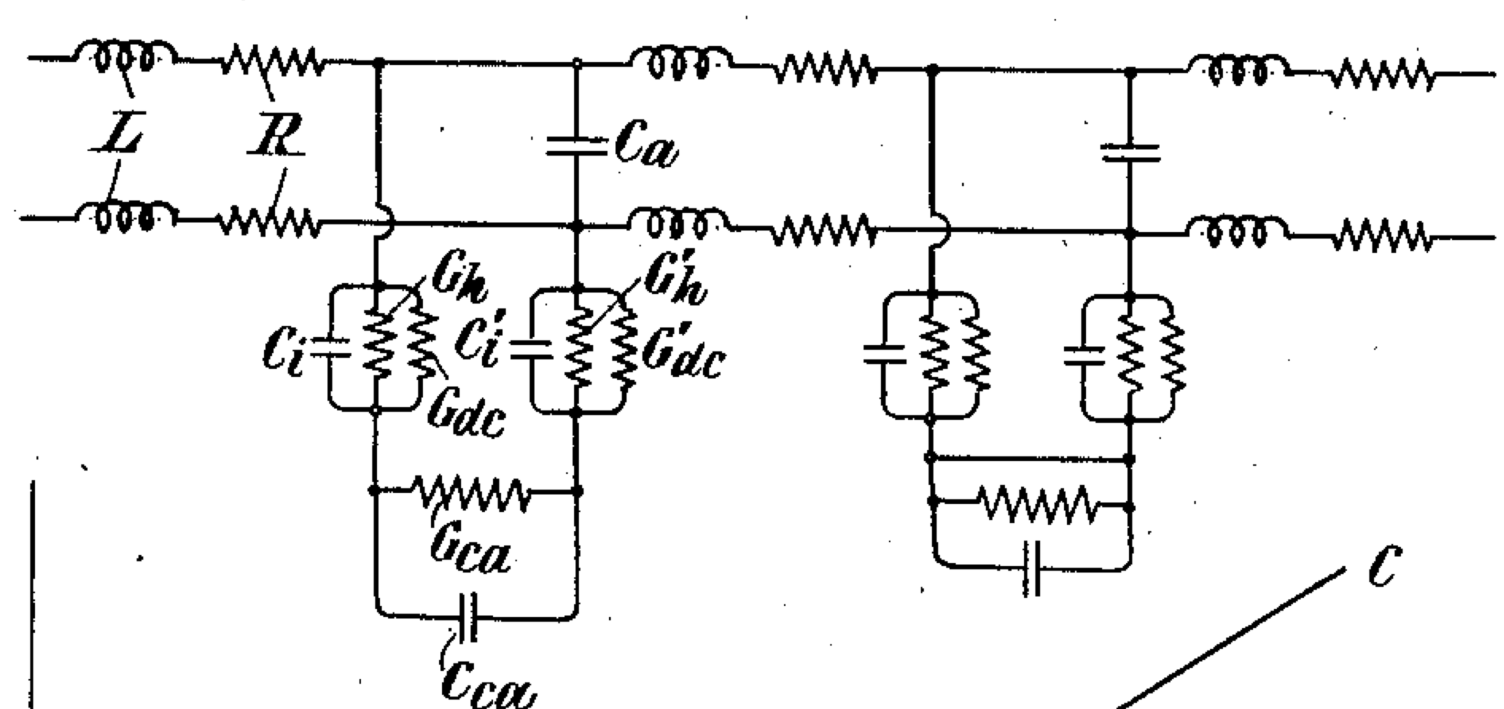

Fig. 6

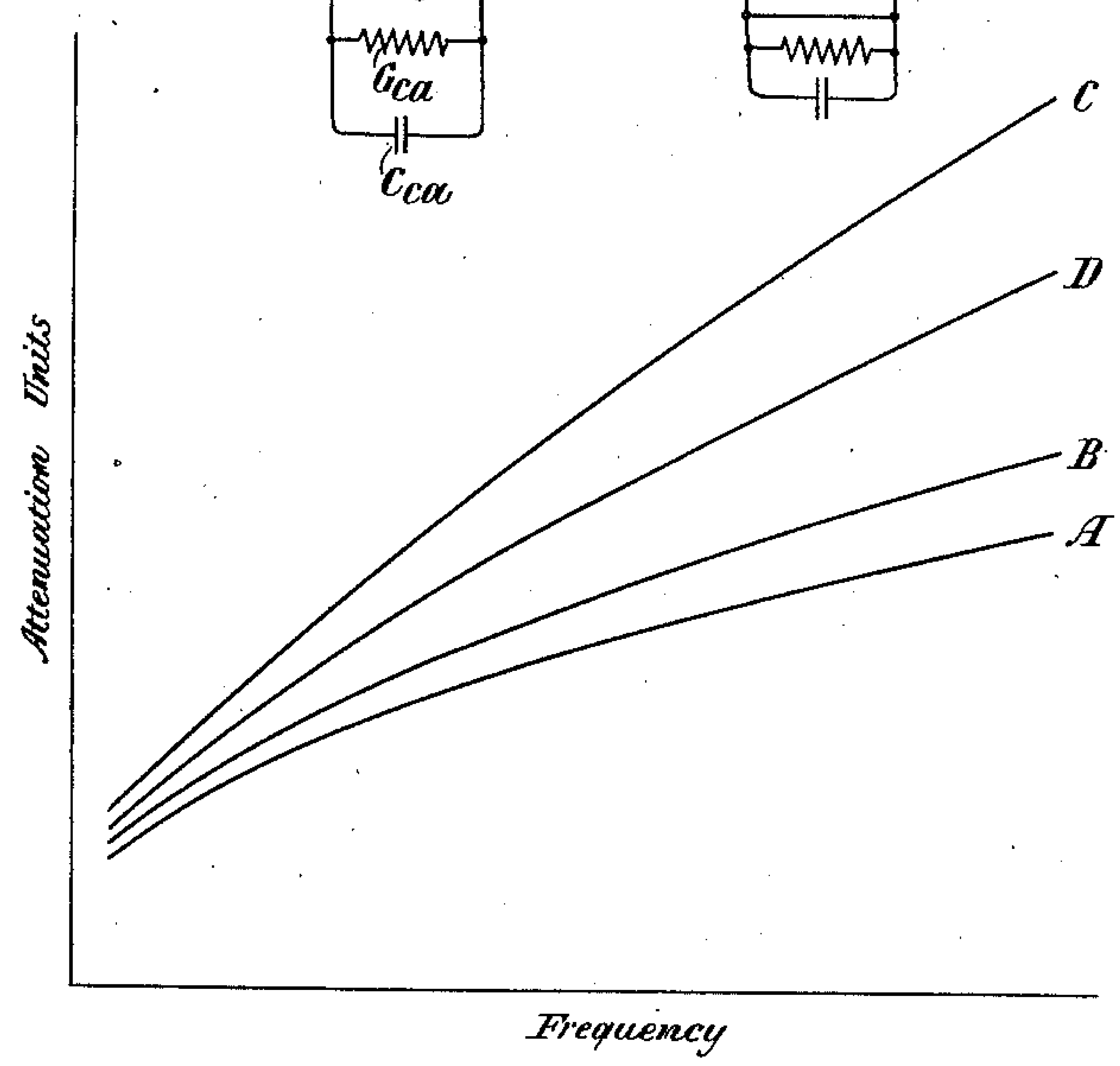

Fig. 7

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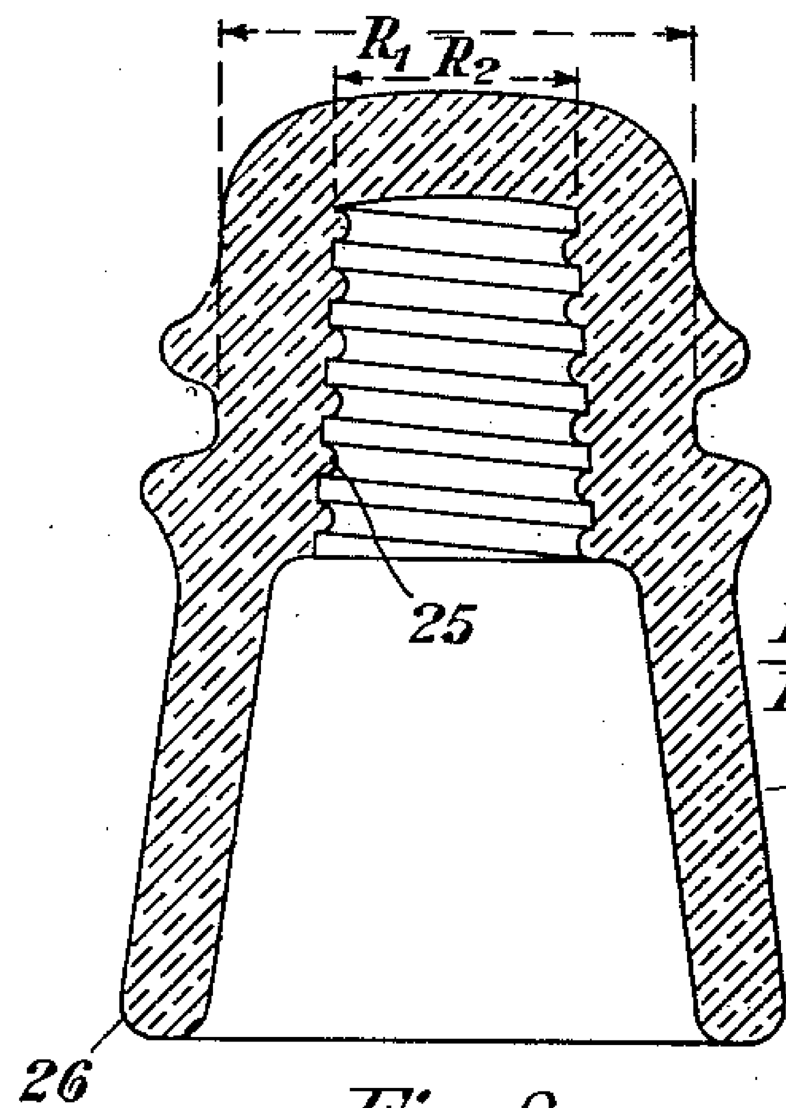
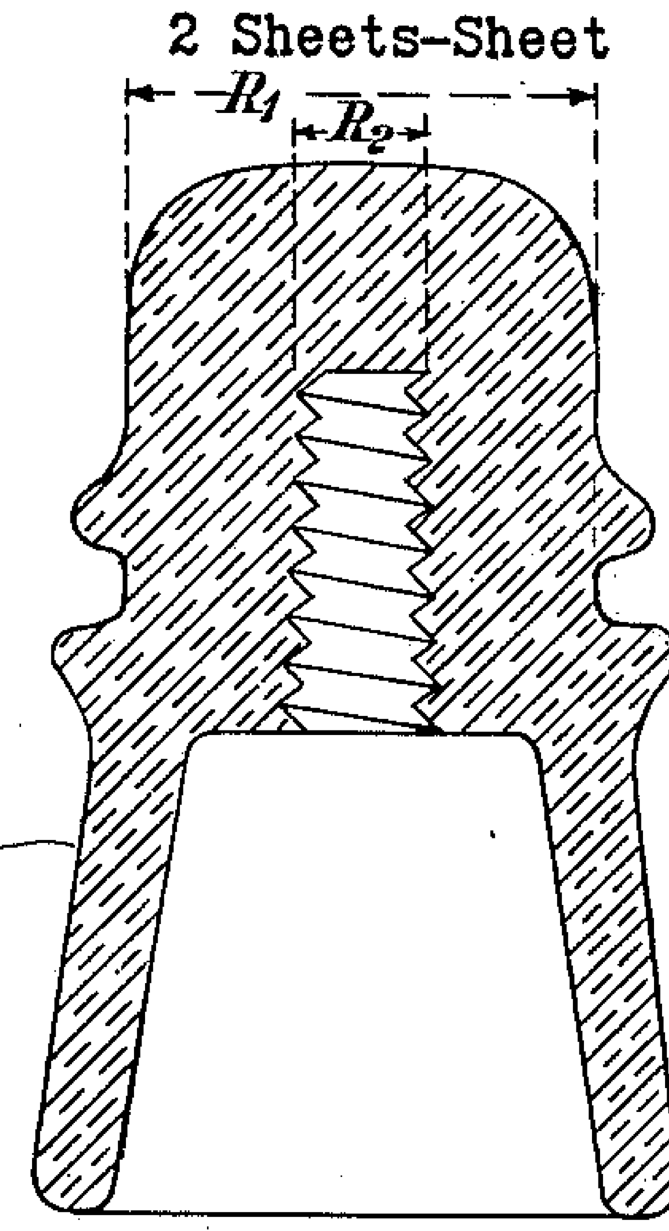
REDUCTION OF LOSSES IN INSULATORS, PINS, AND CROSS ARMS

Filed July 1, 1925 2 Sheets-Sheet 2



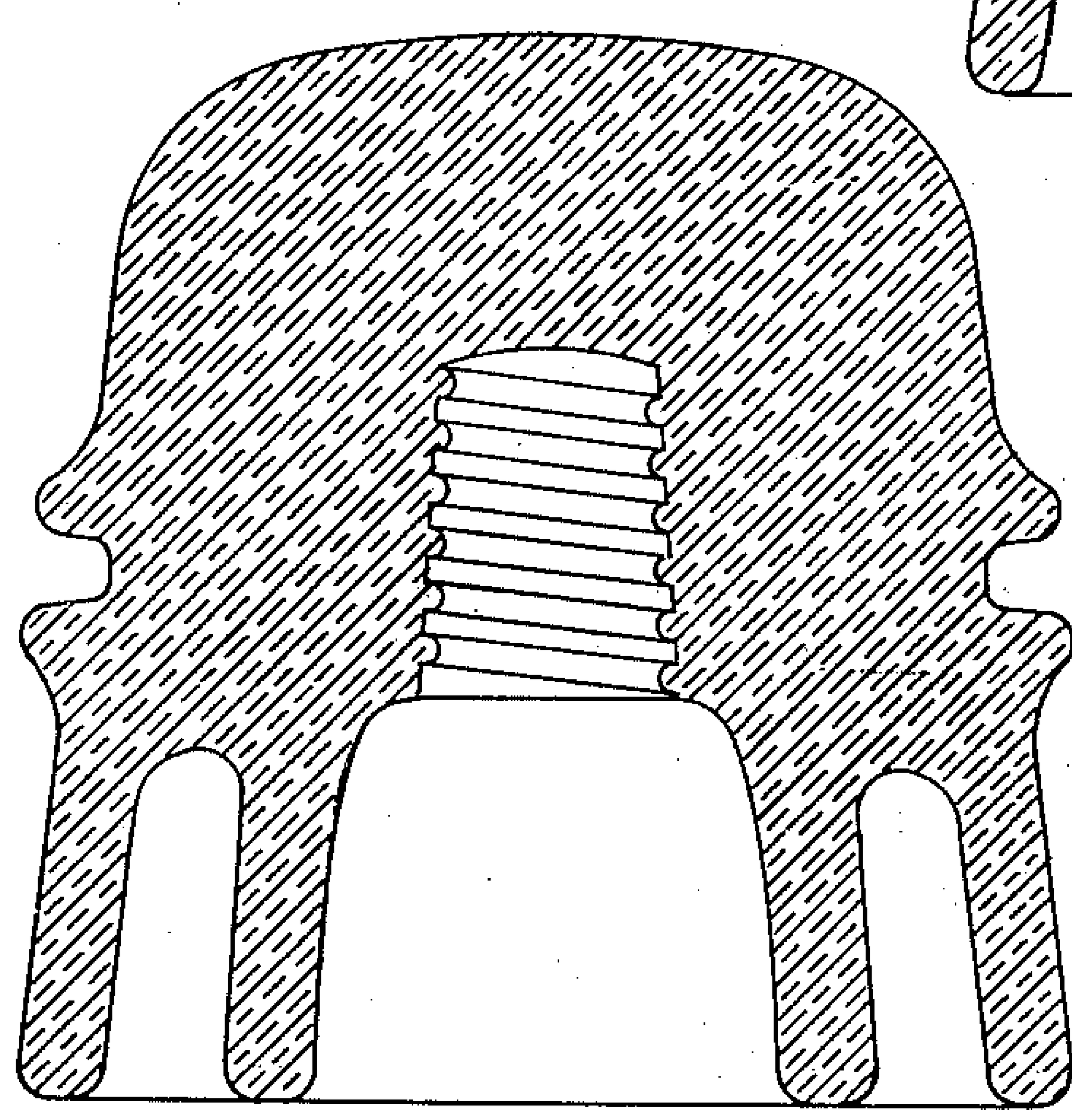
$\frac{R_1}{R_2} = 2$ (approx).

Fig. 8



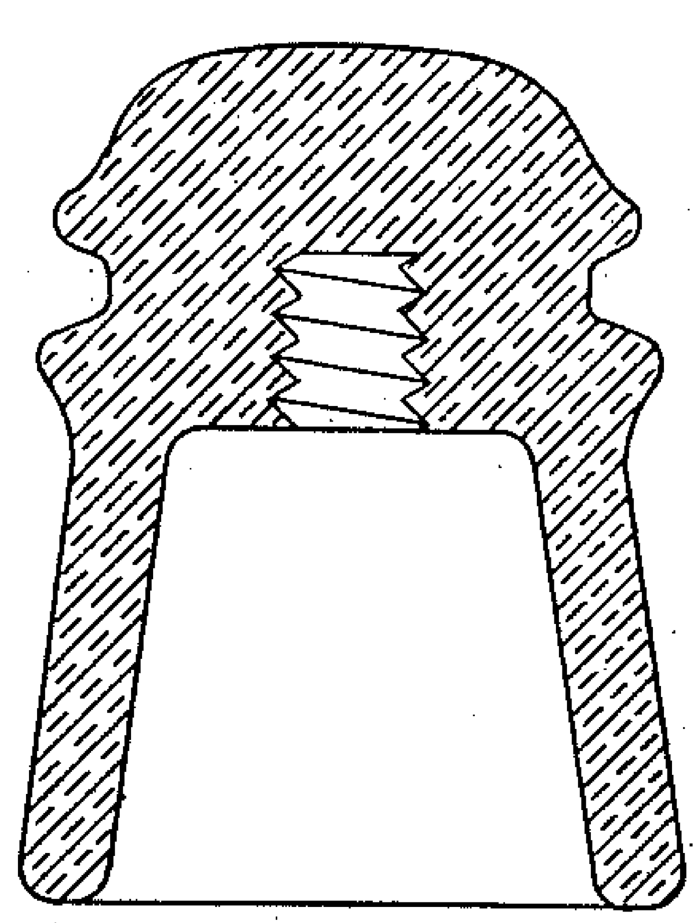
$\frac{R_1}{R_2} = 4$ (approx).

Fig. 9



$\frac{R_1}{R_2} = 4$ (approx).

Fig. 10



$\frac{R_1}{R_2}$ = 4 (approx) and effective height = $\frac{1}{2}$ of that in Fig. 1.

Fig. 11

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UNITED STATES PATENT OFFICE.

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REDUCTION OF LOSSES IN INSULATORS, PINS, AND CROSS ARMS.

Application filed July 1, 1925. Serial No. 40,934.

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

With the development of methods of transmitting telegraphic and telephonic signals by means of carrier currents propagated along open wire lines new transmission problems have been introduced. Owing to the 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 attenuation 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 the terminal stations at which the carrier apparatus is applied. Furthermore, the attenuation is so great that it has been impractical to employ on telephone lines carrier frequencies much above 30,000 cycles per second.

An analysis of the factors producing this attenuation shows that there are three principal factors entering into it,—first the 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.

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 these factors, sometimes referred to as the hysteresis loss of the material of the insulator, and the losses occurring in the cross-arms and insulator pins may be reduced and practically eliminated by the methods and arrangements constituting the subject matter of the present invention.

The invention may now be more fully understood from the following description when read in connection with the accompanying 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 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 circuits illustrating the factors that enter into the propagation of alternating currents along transmission lines; Fig. 7 is a series of curves illustrating the advantages derived by the use of the present invention; Fig. 8 is a view showing the type of insulator ordinarily employed in telephone lines, while Figs. 9, 10 and 11 illustrate insulators of small capacity to be used in connection with the present invention.

Referring to Fig. 1, which illustrates in simplified form a typical cross-arm arrangement such as is employed in connection with 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 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 conductors 8 and 9.

In order to understand how the losses arise 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 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 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 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 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_1 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 conductance 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 even at its worse represents a very small element of the total transmission loss; third, the conductance G_h which represents the dielectric hysteresis 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, viz, 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 2 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 connection 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 construction 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 line wires themselves, series resistance R, which is also inherent in 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, 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.

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

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:

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

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 possible, however, by utilizing the principle of the present invention, to materially reduce 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_1 and C_1' 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_i and C_i', 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 will be explained later, all of the conductances associated with the capacities C_i and C_i' may be materially reduced by suitable methods of insulator construction. The conductance G_{ca}, which represents the losses in the wooden insulator pins and the cross-arm, must, however, be eliminated in a different manner. 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 skin effect, 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 so substantially reduced that we have a condition more or less 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 the transmission regulators for maintaining the transmission constant under different weather conditions will not be necessary.

The curve D represents a variation of the attenuation in 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.

Suitable methods of insulator construction will now be described whereby the transmission loss represented by the curve D may be materially reduced even during wet weather conditions.

The loss represented by the difference between curves A and D is in a large measure due to what is known as the hysteresis loss of the dielectric constituting the insulator. This dielectric hysteresis is somewhat analogous to the hysteresis loss encountered in magnetizing iron. While the phenomenon is not wholly understood, it apparently produces an effect equivalent to the loss introduced by a conductance in the insulator path. This conductance increases with frequency and is proportional to the capacity of the insulator acting as a condenser.

It follows, therefore, that if the insulator is so designed mechanically that its capacity is reduced, there will be a corresponding reduction in the hysteresis loss due to the dielectric of the insulator.

As has already been stated, the capacity of the insulator is due to the surface of the insulator pin acting as one plate of a condenser, the tie wire and line conductor acting as the other plate. The external conducting surface comprising the line conductor and tie wire is, in effect, greatly increased in area during wet weather due to the moisture on the external surface of the insulator.

Referring to Fig. 8, for example, the effect is that of a condenser comprising a dielectric in the form of an insulator, as shown, with an internal, cylindrical, conductive area corresponding to its inner screw-threaded surface at 25, and an external, cylindrical, conductive surface extending from the top of the insulator to the lower margin of the petticoat at 26. Owing to the fact, however, that air, whose dielectric constant is much smaller than that of insulating materials, occupies part of the space between the lower part of the pin and the outer surface of the insulator, the effective capacity may be considered as between a conducting surface in contact with the pin cavity of the glass, and that part of the exterior surface which is immediately opposite. Neglecting the top of the insulator, this may be taken as representing approximately a condenser comprising two concentric cylindrical conductors separated by a dielectric. For such a condenser, the diameter of the outer cylinder being R_1 and the diameter of the inner cylinder being R_2, the capacity will be

$$C=\frac{0.2416KL}{\log_{10}\frac{R_1}{R_2}}$$

(see page 236, Circular No. 74 of the Bureau of Standards). In the foregoing expression K is the dielectric constant and L is the length of the cylinder. From this equation it is clear that the capacity will be reduced if we increase the ratio of R_1 to R_2. Consequently, in an insulator of the type shown in Fig. 8, the capacity will be reduced and consequently the dielectric loss will be reduced if we increase the ratio of the outer diameter to the inner diameter.

It will be at once apparent, however, that this ratio cannot be increased indefinitely, for obvious mechanical reasons. Furthermore, the decrease in capacity is not directly proportional to the increase in this ratio but is proportional to the increase in the longarithm of the ratio. Let us assume, as is indeed the case in practice, that the ordinary telephone insulator is so designed that the ratio of R_1 to R_2 is about 2, (the external diameter of the insulator at the tie-wire groove being approximately two inches and the diameter of the pin cavity being about one inch). Then

$$\log\frac{R_1}{R_2}=0.3010$$

In order to obtain a 2 to 1 reduction of the capacity the diameters must be so chosen that

$$\log\frac{R_1}{R_2}=.6021$$

or, in other words, the ratio of the outer to the inner diameter must be 4. This change in the ratio may be readily accomplished without changing the external shape of the insulator by using a metallic insulator pin so that the diameter of the inner screw-threaded opening will only be about one-half inch, as shown in Fig. 9. At the same time, in order to reduce the capacity between the top of the pin and the top of the insulator, the top of the insulator has been raised. As already stated, it is desirable, in any event, to use a metal supporting pin in order to readily short-circuit the conductance of the cross-arm. Such a design will reduce by about one-half the loss due to dielectric hysteresis or, in other words, the loss represented by the difference between the curve A and the curve D of Fig. 7. The same result may also be obtained by a design such as that shown in Fig. 10, in which the inner diameter is the same as that of Fig. 8 but the outer diameter is twice as great as that of Fig. 8 and the top of the insulator has again been raised; in other words, we may reduce the capacity, and hence the hysteresis loss, one-half by doubling the outer diameter or by making the inner diameter one-half as great. The capacity between the outer surface and the pin cavity for such an insulator would be about 17 mmf. as compared with 35 mmf. for the present insulator.

It is not practical, however, to proceed much further along these lines of design by reason of the fact that the reduction in capacity is proportional to the logarithm of the ratio of the outer to the inner diameter. For example, if it were desired to effect a 5 to 1 reduction it would be necessary that

$$\log\frac{R_1}{R_2}=1.505$$

Hence, the ratio of the outer to the inner diameter must be 32; in other words, although it happens that for the case in which we double the ratio the loss can be reduced by one-half it is necessary to raise the ratio to the fifth power in order to reduce the loss one-fifth.

Some additional reduction in capacity may be obtained, however, if the height of the inner opening for the supporting pin be reduced. It is, of course, apparent that the capacity of the condenser depends upon the area of the plates. If we decrease the height of the opening for the supporting pin we correspondingly reduce the area of the effective inner plate of the condenser. For example, in Fig. 11 an insulator is shown in which the ratio of the outer to the inner diameter is 4, this effect being obtained by reducing the inner opening to one-half the usual diameter and at the same time the height of the opening is made only one-half that of Fig. 1, so that the area of the inner plate surface is reduced one-half. This, of course, produces a further material decrease in the capacity and hence a decrease in the dielectric loss.

Referring to the curves of Fig. 7, if the loss be reduced from that shown by the curve C to that shown by the curve D by short-circuiting the conductance of the cross-arm and pins, as already described, it will be apparent that the loss under wet weather conditions, represented by the curve D, if reduced one-half, will not be materially greater than the loss under dry weather conditions, indicated by the curve B, and such a reduction in loss may be effected by the novel insulator designs just described. In any event the loss due to hysteresis in wet weather, may by this construction, be reduced to a value not materially greater than one fourth of the losses due to the line wires at 30,000 cycles. Not only will there be a very considerable reduction in the maximum loss, but the variation in loss with changes in the condition of the weather will become much less, so that arrangements for regulating the transmission may be dispensed with and a lesser number of repeaters may be used.

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. A pole line construction comprising conductors strung along a pole line in pairs, the conductors being mounted upon insulators supported by pins carried by cross-arms upon the poles, one conductor of each pair acting as a return for the other, and means to reduce the transmission loss over the conductors, said means comprising insulators the ratio of whose external diameter to pin diameter is not much less than 4, in combination with a non-magnetic conductor for substantially short-circuiting the conductance of the cross-arms and supporting pins.

2. A pole line construction comprising conductors strung along a pole line in pairs, the conductors being mounted upon insulators supported by pins carried by cross-arms on the poles, one conductor of each pair acting as a return for the other, and means to reduce the transmission loss over the conductors, said means comprising insulators the ratio of whose external diameter to pin diameter is approximately 4, in combination with a non-magnetic conductor for substantially short-circuiting the conductance of the cross-arms and supporting pins.

3. A pole line construction comprising conductors strung along a pole line in pairs, the conductors being mounted upon insulators supported by pins carried by cross-arms upon the poles, one conductor of each pair acting as a return for the other, and means to reduce the transmission loss over the conductors, said means comprising insulators the ratio of whose external diameter to pin diameter is approximately four, and the thickness of whose dielectric above the top of the pin is substantially the same as the thickness of the dielectric around the pin, in combination with a non-magnetic conductor for substantially short-circuiting the conductance of the cross-arms and supporting pins.

In testimony whereof, we have signed our names to this specification this 29th day of June, 1925.

HERMAN A. AFFEL.
ESTILL I. GREEN.