

May 12, 1959

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2,886,628

ELECTRICAL CONDUCTOR HAVING TRANSPOSED CONDUCTING MEMBERS

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2 Sheets-Sheet 1

FIG. 1

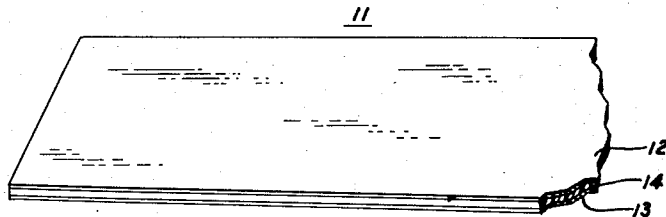


FIG. 2

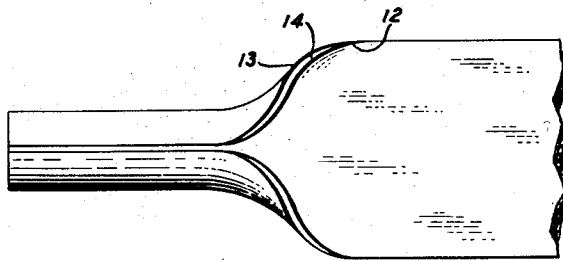


FIG. 3

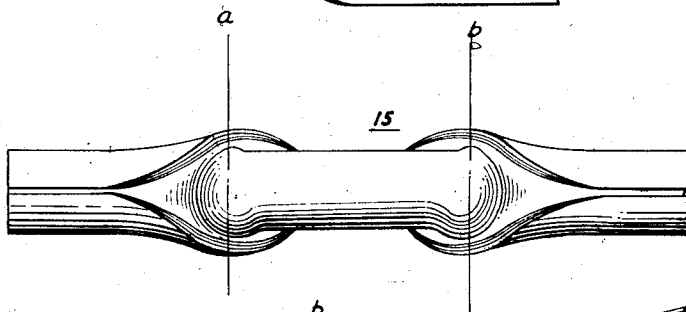
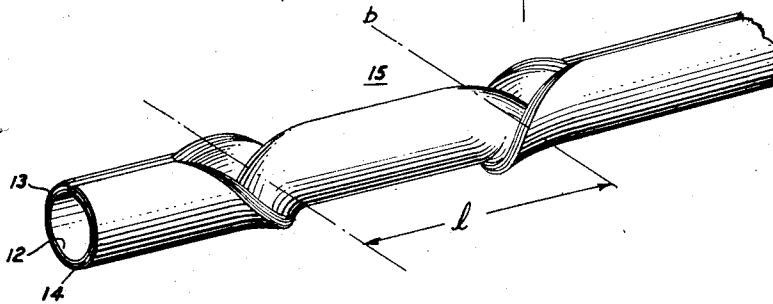


FIG. 4



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FIG. 5

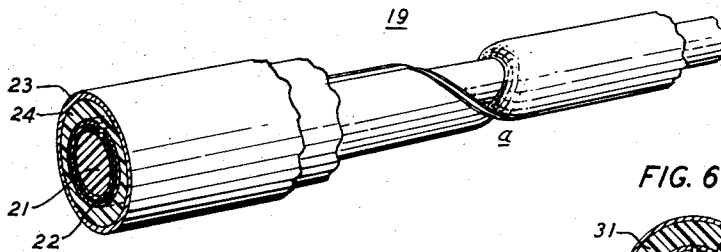


FIG. 6

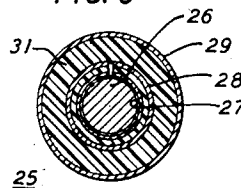


FIG. 7

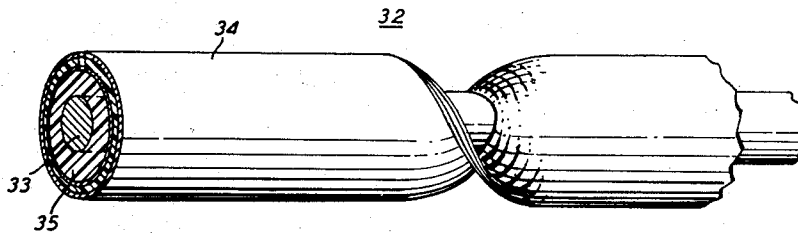


FIG. 8

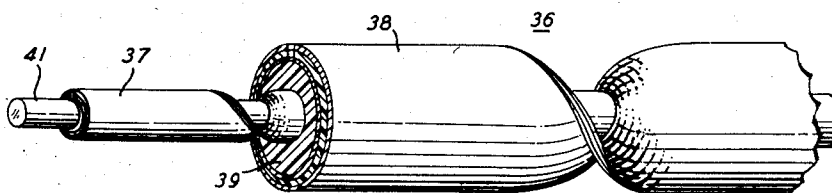
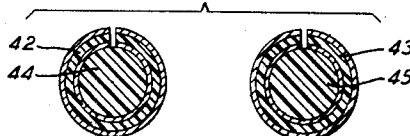


FIG. 9



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ELECTRICAL CONDUCTOR HAVING TRANSPOSED CONDUCTING MEMBERS

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Application June 30, 1955, Serial No. 519,206

3 Claims. (Cl. 174-34)

This invention relates to electrical conductors and, more particularly, to electrical conductors each comprising a plurality of transposed conducting elements, and to methods of making them.

The term "transposed conducting elements" is used to refer to a plurality of conducting elements whose positions are shifted relative to each other and to an axis of the conductor. The shifting may be continuous along the length of the conductor, or it may occur at discrete intervals. Also, the transposition may take the form of frequent shifting of large numbers of conducting strands, as in the case of Litzendraht wire, or it may be an orderly change of position of a few conductors such as, for example, the type shown and described in my co-pending United States patent application Serial No. 366,510, filed July 7, 1953, now Patent 2,812,502 issued on November 5, 1957.

It is an object of this invention to simplify the construction of electrical conductors having transpositions.

It is another object of this invention to provide an electrical conductor the alternating-current resistance of which is less dependent upon frequency changes than that of conventional conductors.

In the transmission of electromagnetic waves, the current distribution, which is substantially uniform throughout the cross-sectional area of the conductor at very low frequencies, becomes nonuniform as frequency is increased. Consider, for example, the case of a solid conductor to which are applied waves of increasing frequency. At direct current and at very low alternating current frequencies, the current is substantially uniformly distributed throughout the cross-sectional area of the conductor, and the resistance of the conductor, and hence the conductor loss, is at a minimum. As the frequency is increased, the current density becomes a maximum at that surface of the conductor which is exposed to the main field of the waves, which, in the present example, is the outer surface, and decreases as distance from the field increases, i.e., towards the center of the conductor. The rate at which the current density decreases is dependent upon the frequency and the material of the conductor, and, for most conducting materials, at high frequencies the current density at the center of the conductor becomes negligible while the current density at the conductor surface is a maximum. This phenomenon is commonly known as "skin effect," and a "skin depth" is defined as the distance measured inwardly from the surface of the conductor in which the current in the conductor will decrease by one neper, i.e., the current density becomes $1/e$ times the density at the surface of the conductor, where e is the natural logarithm base. Because of the skin effect phenomenon, the alternating-current resistance of conductors increases as the frequency increases, becoming quite large at the higher frequencies, necessitating frequent amplification of the signal along the transmission path.

It has been long recognized that the alternating-current resistance of a conductor to high frequencies can be sub-

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stantially reduced if the conductor is formed of a number of conducting elements or members connected in parallel and transposed often so that each conductor receives its share of exposure to the main field. This amounts to forcing the current to distribute itself over the entire cross-sectional area of the composite of individual conducting elements, thereby increasing the total current carrying area. It follows then that the alternating-current resistance is decreased substantially, and the frequency dependency of the alternating-current resistance is likewise decreased.

One well-known example of a composite conductor which utilizes the foregoing principles is Litzendraht wire, which, while effective at lower frequencies, suffers from many disadvantages at the higher frequencies. First, each individual strand of wire must be insulated from all of the others, requiring great care in fabrication, especially for operation at the higher frequencies. Second, for effectiveness at the higher frequencies, the diameters of the individual strands of wire must be made so small that of necessity there are great sacrifices in strength and ruggedness. Third, with the large number of individual strands involved, proper transposition is exceedingly difficult to achieve, especially when use at high frequencies is contemplated, which requires numerous transpositions at very short intervals.

In accordance with the present invention, an electrical conductor having transposed conducting elements is provided which is a great improvement in many respects over other known transposed conductors. In an illustrative embodiment of the invention, a thin flat elongated sheet of dielectric material is interposed between two thin flat sheets of conducting material, forming a flat, elongated "sandwich." The "sandwich" is then rolled into the shape of an elongated hollow cylinder, with the two edges of the "sandwich" in close proximity, forming a longitudinal seam or slot. At intervals along its length the cylinder is turned inside out and reformed into cylindrical shape, with what was the inner conductor becoming the outer conductor, and what was the outer conductor becoming the inner.

The invention will be more readily understood by referring to the following description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a perspective view of the arrangement of conductors and insulators into a "sandwich" out of which the several preferred embodiments of the invention are made;

Fig. 2 is a plan view of an intermediate step in the formation of a preferred embodiment of the invention;

Fig. 3 is a plan view of a preferred embodiment of the invention showing a single composite conductor with transposed conducting elements;

Fig. 4 is a perspective view of the conductor of Fig. 3;

Fig. 5 is a perspective view of a coaxial cable embodying the principles of the invention;

Fig. 6 is a cross-sectional view of a modified form of the cable of Fig. 5;

Fig. 7 is a side view of a coaxial cable embodying the principles of the present invention;

Fig. 8 is a side view of still another coaxial cable embodying the principles of the present invention; and

Fig. 9 is a cross-sectional view of the composite conductor of the present invention as used in a twin wire transmission line.

Turning now to Fig. 1, there is shown a composite conductor 11 comprising two thin, flat elongated sheets 12 and 13 of conducting material, such as copper, separated by a thin, elongated sheet 14 of dielectric or insulating material. Sheet 14 may be of any one of a number of suitable materials, such as polystyrene, which have relatively low dielectric constants. Conducting

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sheets 12 and 13 are preferably bonded to dielectric sheet 14 to form a permanent composite conductor. The bonding may be accomplished by any one of a number of processes well known in the art, such as vapor deposition or plating the conducting material onto the dielectric, or by use of suitable adhesive material. The thickness of conductors 12 and 13, and of dielectric 14 are preferably of the order of one skin depth at the highest frequency of operation of the conductor, although some variation in thickness is permissible.

In Figs. 3 and 4 there is shown a transposed conductor 15 which has been formed from the composite conductor 11 of Fig. 1 in the following manner. Conductor 11 is rolled into the shape of a hollow cylindrical conductor with the two edges in proximity to each other, forming a longitudinal slot or seam. It is not necessary that the edges abut each other. At intervals along the length of cylindrical conductor 15, the slot is spread as best seen in Fig. 2 and the cylinder is inverted, i.e., turned inside out, as best seen in Figs. 3 and 4 at points *a* and *b*. It should be noted that conductor 15 is widest at points *a* and *b* as illustrated in Figs. 3 and 4. The width at these points on the conductor will be determined by the material used and the method of forming the inversion, and need not be substantially greater than the outside diameter of the remainder of conductor 15. The slot which, in Fig. 2, is shown at the top of cylindrical conductor 15 in the first portion of its length, is situated at the bottom of the cylinder after the transposition at point *a*, and again at the top after the transposition at point *b*. This 180-degree shift of the seam occurs at each transposition throughout the length of the conductor 15. It can readily be seen in Figs. 3 and 4 that, after the transposition at point *a*, inner conductor 12 has become the outer conductor, and outer conductor 13 has become the inner conductor, thus effecting a complete transposition. If the main field along the conductor is at the outer surface, and if the intervals between transpositions remain the same throughout the conductor length, it is obvious that conductors 12 and 13 are made to share equally exposure to the main field.

The effectiveness of transposition of conducting elements in a conductor depends to a considerable extent upon a judicious selection of the transposition interval, that is, the distance, 1 between the points *a* and *b* in Figs. 3 and 4. It is desirable to transpose often enough to insure a substantial reduction in losses, yet, on the other hand, in the interests of ease and low cost of fabrication, it is desirable that the conducting elements be transposed no more frequently than is necessary. As long as the currents carried by the conducting elements are approximately equal, losses will be minimized, hence it is necessary to transpose only often enough to maintain this condition of approximate equality of currents in the conducting elements. In the drawings of the present invention, the particular embodiments shown are neither to scale nor proportion, inasmuch as the transposition interval may be quite long as compared to that portion of the length of the conductor over which the transposition is accomplished.

In Fig. 5 there is shown a coaxial cable 19 having a dielectric core 21, a composite inner conductor 22, an outer conductor 23 spaced from the inner conductor 22, and a dielectric 24 filling the space between the inner and outer conductors. Dielectric 24 may be a solid dielectric or it may be air, in which case conductors 22 and 23 are spaced from each other by dielectric spacers, not shown, of the type well known in the art. In the cable of Fig. 5, inner conductor 22 is the type of composite conductor shown in Figs. 3 and 4, having periodic transpositions of its conducting elements along its length. It is necessary to pierce conductor 22 in the manner shown at point *a* in Fig. 5 to permit passage of core 21. Piercing conductor 22 in this manner has a negligible effect on the overall efficiency of the arrangement.

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In Fig. 6 there is shown a coaxial cable 25 having a core 26 of metal, a composite inner conductor 28 separated from the core 26 by a thin layer of insulating material 27, and an outer conductor 29 separated from inner conductor 28 by dielectric material 31. As was the case in the cable of Fig. 5, dielectric 31 may be of solid dielectric material, or it may be air, in which case dielectric spacers are used to maintain conductors 28 and 29 in spaced relationship. Inner conductor 28 is of the type shown in Figs. 3 and 4, having periodic transpositions of its conducting elements along its length. Core 26 is preferably of a metal having good conducting properties, in which case it contributes to the conduction of the inner conductor, and can also be used to carry power currents. Where mere mechanical strength alone is desired, core 26 can be made of any suitable material. As was the case in the cable of Fig. 5, the inner conductor 28 must be pierced at the transposition points to permit passage of the core 26. The insulating layer 27 on core 26 effectively prevents any metal to metal contact at the transposition points.

In Fig. 7 there is shown a coaxial cable 32 having a solid inner conductor 33 and a composite outer conductor 34 separated from inner conductor 33 by a dielectric 35. Outer conductor 34 is similar to composite conductor 15 of Figs. 3 and 4 except that it is pierced at the transposition points in a manner similar to the inner conductors of the cables of Figs. 5 and 6 to permit passage of the solid inner conductor and the dielectric. As was the case with the conductors of Figs. 5 and 6, dielectric 35 may be of any suitable material, or it may be air, in which case dielectric spacers are used, and it is only necessary to pierce conductor 34 sufficiently to permit passage of conductor 33.

Fig. 8 shows a coaxial cable having a core 41, an inner composite conductor 37 and an outer composite conductor 38 separated therefrom by a dielectric 39. Dielectric 39 may be any suitable material or air, as was the case in Figs. 5, 6 and 7. In the cable of Fig. 8, both conductor 37 and conductor 38 are similar to composite conductor 15 of Figs. 3 and 4. Obviously, conductor 38 must be pierced at the transposition points. Core 41 may be of dielectric material or metal, depending upon the uses to which the cable is to be put. If core 41 is of metal, a thin coating of insulation, not shown, is desirable. It is necessary that conductor 37 be pierced at the transposition points to permit passage of core 41.

Figs. 5, 6, 7, and 8 all have dealt with the adaptation of the composite conductor of Figs. 3 and 4 to coaxial cables. However, the conductor of Figs. 3 and 4 is readily adaptable to practically any current carrying conductor arrangement. For example, there is shown in Fig. 9 a parallel pair transmission line comprising composite conductors 42 and 43 mounted on cores 44 and 45 respectively. Conductors 42 and 43 are like the conductor of Figs. 3 and 4, but are pierced at the transposition points to permit passage of cores 44 and 45. Cores 44 and 45 may be either of metal or dielectric material like the core 41 of Fig. 8.

In all of the embodiments of the invention herein shown, the use of insulating material surrounding the cables, or of metallic sheathing is permissible. There has been no showing of any insulator or sheathing inasmuch as such practices are well known in the art and have, therefore, been omitted for the sake of clarity.

It is to be understood that the above-described arrangements are merely illustrative of the application of the principles of the invention, and applicant does not intend to limit his invention to the particular embodiments herein shown. Numerous other embodiments may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A low loss electrical conductor of cylindrical form comprising laminations of conducting material separated

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by a sheet of insulating material, alternate sections of the conductor being formed by the composite laminations being bent in opposite directions to form cylinders, one of said laminations being on the inside in one of said sections and the other of said laminations being on the inside in an adjacent section.

2. A low loss electrical conductor having a plurality of sections comprising continuous laminations of conduction material throughout said sections, insulating material separating said laminations of conduction material, said laminations being formed into substantially cylindrical portions throughout each of said sections with one lamination being surrounded by another lamination in one of said sections and said other lamination being surrounded by said one lamination in an adjacent one of said sections. 15

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3. A low loss electrical conductor comprising laminated cylindrical sections of conducting material, said conducting material separated by insulating material, the conductor being slotted through the laminations and insulation for the entire length thereof, the slot of adjacent sections being at diametrically opposite points, and one of said laminations being on the inside in one of said sections and the other of said laminations being on the inside in adjacent sections.

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