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ELECTRICAL CONDUCTOR HAVING TRANSPOSED CONDUCTING ELEMENTS

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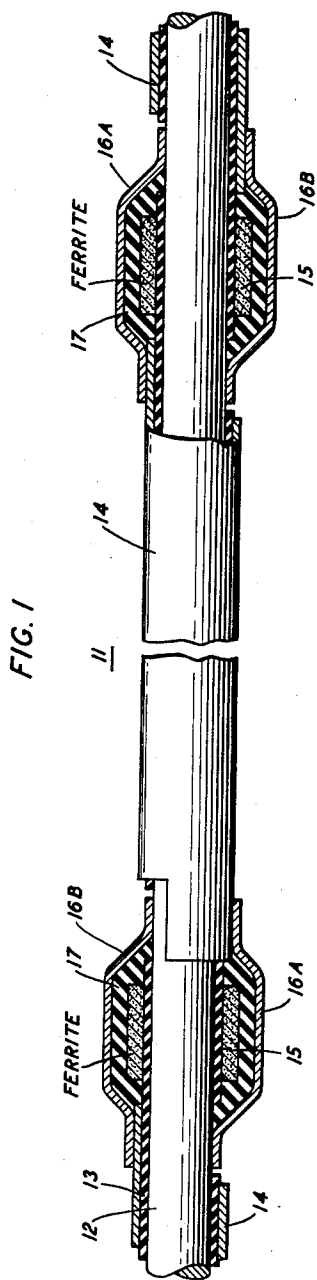
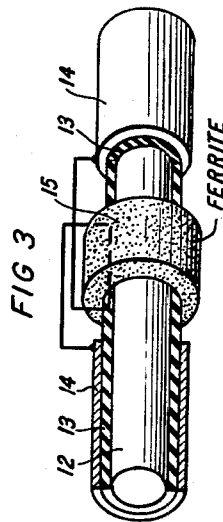


FIG. 2



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ELECTRICAL CONDUCTOR HAVING TRANSPOSED CONDUCTING ELEMENTS

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9 Claims. (Cl. 333-96)

This invention relates to electrical conductors, and, more particularly, to electrical conductors having electrical transpositions along the length thereof.

The term "electrical transpositions" is used to refer to a transferring of the currents amongst a plurality of conducting elements whose positions relative to the main fields of the wave transmitted are constant, so that, on the average, the main fields will influence the currents in the conducting elements equally. The transferring may be continuous along the length of the conductor, or it may occur at discrete intervals. Also, electrical transposition may take the form of frequent interleaving of large numbers of conducting strands, as in the case of Litzendraht wire, or it may be an abrupt change of position such as, for example, the type shown and described in my copending United States Patent application Serial No. 366,510, filed July 7, 1953, now United States Patent 2,812,502, issued November 5, 1957, in which case the position of the current carrying conductors is not constant relative to the main field of the waves.

It is an object of this invention to provide an electrical conductor of simple construction having electrical transpositions occurring at intervals along its length.

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 fields 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 at 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 the 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 substantially 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 Litz 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 diameter 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 electrical transpositions is provided which is a great improvement in many respects over other transposed conductors. In an illustrative embodiment of the invention, a solid conducting core member is surrounded by a succession of longitudinally disposed conducting members which are spaced along and separated from the core member by insulating material. In the spacing between each pair of successive surrounding members is disposed a cylinder of material having high permeability and low conductivity. The cylinder in turn surrounds the core member and is insulated therefrom. Bridge members connect the surrounding conducting member on one side of the cylinder of magnetic material to the core member on the other side of the cylinder of magnetic material, thereby effecting a transposition of the currents being carried in the core member and the surrounding conducting members without breaking or interrupting the core member. As a result the mechanical strength of a solid core member is obtained, while the advantages of a transposed conductor are realized.

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

Fig. 1 is a side elevation, partially cross-sectional view of a conductor embodying the principles of the present invention;

Fig. 2 is a perspective view of an element of the conductor of Fig. 1 by which transpositions are effected, and

Fig. 3 is a perspective view partially in section of another conductor embodying the principles of the invention.

Turning now to Fig. 1, there is shown a composite conductor 11 comprising an elongated core member 12 of conducting material, such as copper, surrounded throughout its length by a thin layer 13 of suitable insulating material. It is to be understood that core member 12 may be of any suitable material having sufficient structural strength, so long as there is a sufficiently thick layer of conducting material thereon. For example, core member 12 might be of copper-clad steel, or might be of solid

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dielectric material with a layer of conducting material plated on its surface. Surrounding insulating layer 13 are a succession of longitudinally spaced cylindrical sleeves 14 of conducting material. Between the ends of each pair of adjacent sleeves 14 and surrounding the insulating layer 13 is a cylindrical member 15 of magnetic material. As will be more apparent hereinafter, member 15 is advantageously of a material having a high magnetic permeability and a very low electrical conductivity. In general, the operation of the conductor of the present invention will be enhanced the higher the permeability and the lower the conductivity. Typical of such materials are the ferrites, which are relatively homogeneous crystal compounds comprising the reaction product of iron oxide and at least one other metallic oxide. Such materials exhibit permeabilities in the thousands and very low values of electrical conductivity.

In order that transposition of the currents being carried in the members of composite conductor 11 can be effected, each of the conducting sleeves 14 is connected, at each of its two ends, across its adjacent member 15 to core member 12 by means of a separate bridge member 16.

As shown in the drawing, each of the members 14 has its left end connected to core member 12 across the adjacent member 15 by a bridge member 16A and its right end so connected by a bridge member 16B. Bridge members 16A and 16B may be of any suitable configuration such as, for example, that shown in Fig. 2, and of any suitable conducting material. Members 16A and 16B are joined to members 12 and 14 in any suitable manner such as, for example, brazing or welding. To facilitate joining members 16 to the member 12, members 14 and insulating layer 13 are cut back slightly, as best seen in Fig. 1. To insure a sufficient mechanical strength and freedom from pockets, the spaces between bridge members 16 and members 15 are preferably sealed with suitable insulating material 17.

In operation, current in member 12 encounters a high series inductance at each transposition point as a direct result of the presence of member 15. This current will, therefore, tend to flow through the bridge member 16 into the next adjacent member 14 instead of flowing through the series inductance. At the same time, the current in the member 14 before the transposition point is connected through a second bridge member 16 to the member 12 beyond the transposition point. It is readily apparent, therefore, that the currents in members 12 and 14 are made to "change places" at the transposition points. If the main field of the wave being transmitted along the conductors is at the outer surface, such as, for example, in the case where conductor 11 is the inner conductor of a coaxial cable, and if the intervals between transpositions remain approximately the same throughout the conductor length, it is obvious that the current in elements 12 and 14 of conductor 11 will behave as though the elements were made to share equally exposure to the main field.

The effectiveness of transpositions in a conductor depends to a considerable extent upon a judicious selection of the transposition interval. 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 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 drawing of the present invention the particular embodiments shown are neither to scale nor to 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.

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In the embodiment of Fig. 1, transpositions are effected by actual electrical connections between the inner and outer conducting members. It is likewise possible to accomplish the desired end of equal currents in the conducting members with no direct electrical connection between them. In such an arrangement, adjacent members 14 are connected by means of a wire which is looped around magnetic member 15 for one turn in such a manner that the current in the wire passes inside the magnetic cylinder 15 in a direction opposite to the current in member 12. The result is a transformer in which the two windings are in opposition. In operation, there is a tendency for current in the inner member 12 to migrate, by means of displacement currents, to member 14. Designating the currents in the two conducting members at the outset as I_a , then the effect of the migration is to increase the current in member 14 by an amount I_b and to decrease the current in member 12 by the same amount. In this case, the impedance of the transformer to the component I_a in each conducting member is given by

$$X_a = j\omega(L - M) \quad (1)$$

where L is the series inductance and M is the mutual inductance, and the impedance of the transformer to the component I_b in each conducting member is given by

$$X_b = j\omega(L + M) \quad (2)$$

If the coefficient of coupling approximates one, which is possible in this case, the impedance to I_b is many times greater than that to I_a . Such an arrangement therefore, acts to counteract the tendency of the current to migrate, and current balance is maintained.

While the particular embodiments herein described are of circular cross section, it is obvious that they may be of any suitable shape, and I do not intend to limit myself to the particular configuration described. In addition, the use of insulation surrounding the conductor, has not been shown for the sake of clarity. It is obvious that such practice is within the purview of the invention.

It is to be understood that the above-described arrangements are merely illustrative of the application of the principles of the invention, and I do not intend to limit my invention to the particular embodiments herein described. 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 comprising an elongated inner member of conducting material, a succession of hollow conducting sleeves spaced apart along the length of said member, said sleeves surrounding said member and being spaced therefrom, magnetic material having high resistivity interposed in the spacing between adjacent said sleeves of the succession, and means of conductive material bridging said magnetic material for forming an electrical connection between each sleeve on one side of the adjacent magnetic material to the inner member on the other side of said magnetic material.

2. A low loss electrical conductor as claimed in claim 1, wherein said magnetic members are of ferrite material.

3. A low loss electrical conductor as claimed in claim 1 wherein said elongated inner member of conducting material comprises a cylindrical member of conducting material surrounding a solid core member.

4. A low loss electrical conductor comprising an elongated inner member of conducting material, a succession of cylindrical conducting sleeves spaced along the length of said member, said sleeves surrounding said member and being spaced therefrom by insulating material, and means for maintaining the currents in said inner member and said sleeves substantially balanced, said means being located along the length of the inner member in the spaces between successive conducting sleeves and introducing a high series inductance to currents flowing in said inner member, and means for transporting cur-

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rents between said inner conducting member and said sleeve members at each end of each sleeve member respectively, said transposing means being connected to said inner member in each case at one side of said high series inductance and to the sleeve member on the opposite side of said inductance.

5. A low loss electrical conductor comprising an elongated cylindrical member of conducting material, a succession of hollow cylindrical sleeves of conducting material spaced apart along the length of said member, said sleeves surrounding said member and being spaced therefrom, magnetic material of high permeability and low conductivity interposed in the spacing between adjacent sleeves of the succession and insulated from said member and said sleeves, and means of conducting material bridging said magnetic material for forming an electrical connection between each sleeve on one side of the adjacent magnetic material to the member on the other side of said magnetic material.

6. A low loss electrical conductor as claimed in claim 5 wherein said magnetic material is a ferrite material.

7. A low loss electrical conductor comprising an elongated member of conducting material, a plurality of conducting means spaced apart along the length of said conducting member, insulating means interposed between said conducting means and said conducting member, and means for maintaining the currents in said conducting member and said conducting means substantially balanced, said means including magnetic cylinders of high permeability and low conductivity surrounding said inner member at the spaces between adjacent of said conducting means and insulated from both said conducting members and said inner member to introduce a high series impedance to currents flowing in said inner member, and means for transposing currents between

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said inner member and said conducting members, said transposing means providing electrical connections between said inner member and said conducting members to bypass the high impedance introduced by said magnetic cylinders.

8. A low loss electrical conductor in accordance with claim 7 wherein said transposing means further includes a conducting bridge extending across said magnetic member and electrically connected between said conducting member on one side of said magnetic member and said conducting means on the other side of said magnetic member.

9. A low loss electrical conductor comprising an elongated member of conducting material, an insulating layer overlying said elongated member, a plurality of distinct conducting means spaced at intervals along the length of said conducting member, magnetic members of high permeability and low conductivity spaced in alternation with said conducting means and along said elongated member, insulating means between said magnetic members and the adjacent conductive members, and bridging members across said magnetic members and insulated therefrom, said bridging members being electrically connected to a conducting member at one side of said magnetic members and to a conducting means at the other side of said magnetic members.

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