

Feb. 1, 1938.

H. W. DUDLEY
STRANDED CONDUCTOR

2,107,177

Filed Nov. 1, 1934

2 Sheets-Sheet 1

FIG. 1

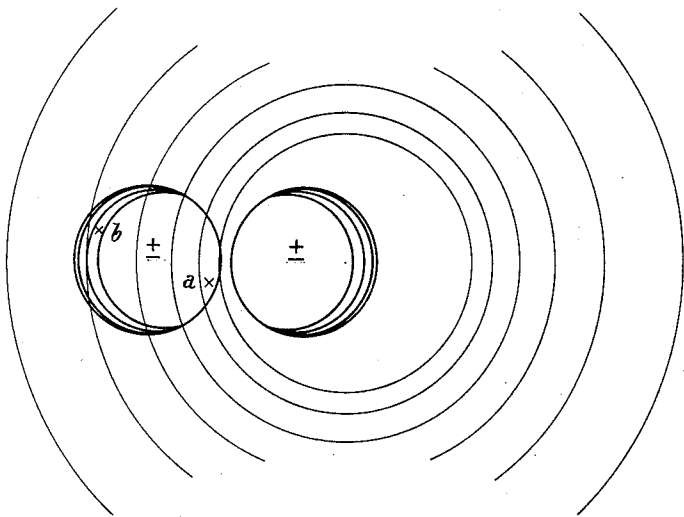


FIG. 2

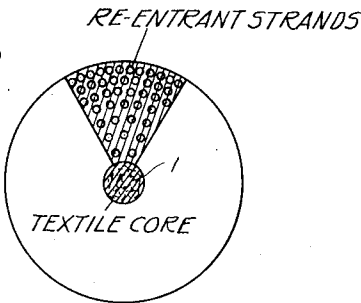


FIG. 2A

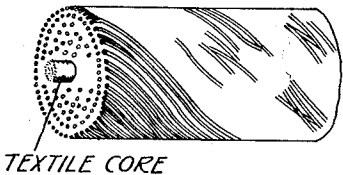


FIG. 4

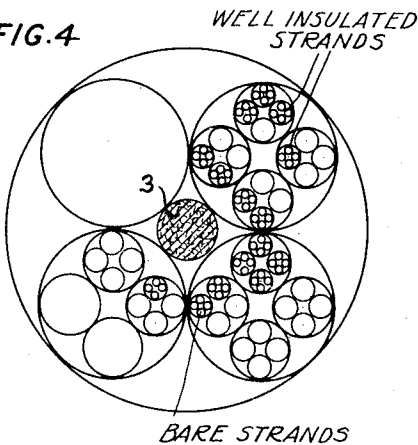
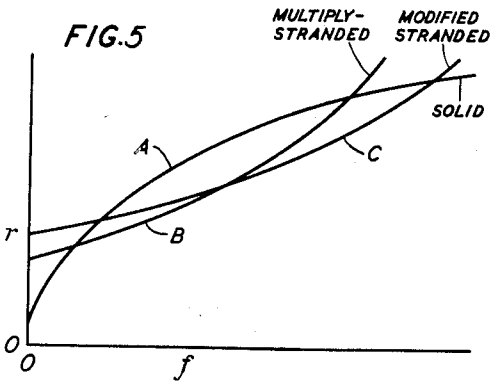


FIG. 5



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FIG. 3

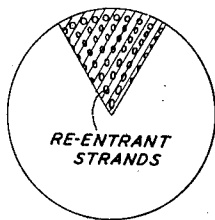


FIG. 3A

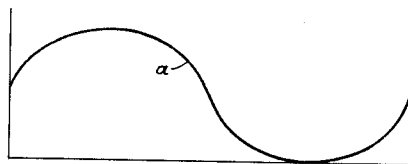


FIG. 3B

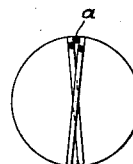
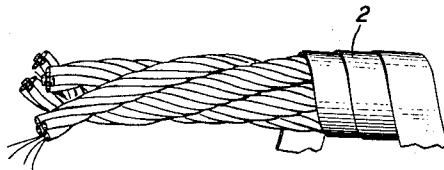


FIG. 4A



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2,107,177

STRANDED CONDUCTOR

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Application November 1, 1934, Serial No. 750,926

1 Claim. (Cl. 173—13)

This invention relates to electrical conductors adapted for the transmission of high frequency waves and more particularly to stranded conductors.

5 The broad object of this invention is to provide a conductor that will transmit high frequency waves with minimum attenuation. A more specific object is to improve the design of stranded conductors so as to adapt them for efficient radio frequency transmission.

10 It is well known that when high frequency currents are transmitted over an ordinary wire conductor, the current is not uniformly distributed throughout the cross-section of the conductor but is concentrated near the surface. As a consequence of this "skin effect", the alternating-current or effective resistance of the conductor is increased above the value that would be obtained if the central portion of the conductor carried its proportionate share of the current. Stranded conductors have heretofore been proposed to avoid the consequences of skin effect. In the usual conductor of this type, a large number of insulated strands of wire are twisted or braided together in such manner that over a given length of conductor each strand occupies every possible cross-sectional position within the interior of the conductor. Thus the current is forced to pass through the central portion of the conductor and a more uniform distribution of current throughout the conductor cross-section is obtained. Energy losses within the conductor accordingly tend to be reduced.

15 It is a matter of experience that stranding loses its effectiveness after a certain frequency is exceeded. Any stranded conductor will be found, in fact, to have a greater effective resistance above a certain frequency than a solid conducting wire of the same overall diameter. Obviously it must be that in every stranded conductor there is present some inherent electrical effect that becomes predominant as a certain frequency is exceeded and that is not overcome by present stranding methods. What that inherent effect is will be explained hereinafter, but it may briefly be stated now to relate to "proximity effect", the effect of current in one strand on the current distribution within other strands.

20 A stranded conductor in accordance with applicant's invention is characterized by the manner of current distribution within the conductor cross-section. Instead of providing the uniform current distribution sought heretofore, the conductor is so designed that the current density decreases from a maximum at the surface of the

conductor to a minimum at the center. Thereby the consequences of proximity effect at high frequency are mitigated and the resistance of the conductor is maintained at a relatively low value over a wider frequency range. This invention is disclosed but not claimed in applicant's U. S. Patent 1,978,419, October 30, 1934. The disclosure of said patent is to be deemed incorporated in the disclosure of this application.

25 The nature of the present invention will appear more fully in the discussion that is to follow. Reference will be made to the accompanying drawings, in which:

Fig. 1 illustrates proximity effect between two solid conducting wires;

Figs. 2 to 4 show schematically stranded conductors in accordance with the invention; and

Fig. 5 shows graphically the variation of effective resistance with frequency for several types of conductors.

30 The nature of proximity effect may be understood by reference to Fig. 1. In this figure is shown how the current tends to distribute itself in two adjacent solid conductor strands carrying high frequency current in the same direction. Within each strand skin effect tends to force the current to the surface of the strand, although this tendency is not nearly so marked as it is in conductors of greater cross-sectional area. At the same time, the electromagnetic field associated with the current in each strand tends to repel the current in the other strand to the outermost portion of that strand. From another aspect, an elemental conducting path at *a* within a strand has a greater inductive impedance than the similar conducting path at *b*, since it is linked to a greater degree by the electromagnetic field surrounding the other strand, and by reason of its greater impedance transmits a lesser portion of the total current. Thus, distortion of the current distribution due to the proximity of other current carrying strands contributes still further to the effective resistance of the conductor.

35 Both skin effect and proximity effect can be reduced by using smaller strands. As regards the skin effect within a strand it is obvious that employing more strands of smaller diameter will yield a direct benefit since the smaller strands carry less current and therefore have less magnetic field within them. As regards proximity effect, the use of more strands of smaller diameter is not so beneficial because the adjacent strands are nearer and more numerous, thus offsetting to an appreciable extent the benefit due to the smaller currents in them. Because of manu-

facturing difficulties the use of smaller strands ceases to be of practical utility when a strand size of about No. 40 B & S gauge enameled wire is reached.

Any stranded conductor has a greater direct current resistance than a solid conductor of the same overall diameter. At moderately high frequencies the current in a solid conductor is forced to the outside leaving part of the conductor carrying less than its proportionate share of the current and so making for a high resistance. Within this frequency range stranding is effective to reduce the resistance of the conductor since by forcing the current toward the center of the conductor the improvement in current distribution more than offsets the effect of reduced copper cross-section. At still higher frequencies, the current distribution throughout the cross-section of the interior strands becomes seriously distorted due to the proximity of adjacent current carrying strands. Eventually a frequency is reached where the current distribution in the interior strands is so non-uniform as to make it undesirable to force currents into the interior strands. Less total resistance is then obtained by permitting all of the current to flow in the outside strands. Still less total resistance can be obtained, however, by forcing a relatively small amount of current through the central strands.

The seriousness of the effect just described can be appreciated from the fact that at 500 kilocycles a conductor comprising 500 strands of No. 40 B & S gauge enameled wire has a greater effective resistance than a simple seven strand conductor would have if proximity effect were absent.

In accordance with the present invention the effective resistance attributable to proximity effect is reduced to a substantial degree by arranging the stranding so that less current per unit of cross-sectional area is carried by the strands at the center of the conductor than by those further out. At first thought it might seem that reducing the current carried in any section of the conductor would be only a waste of available conducting area. Carried to an extreme this would, of course, be the case. At the other extreme, as represented by present practice, however, it is obvious that proximity effect may be so great in the inner strands that the latter may introduce very high resistance losses when they are forced to carry current. Preferably the stranding is so arranged that the current density decreases substantially uniformly from the outer surface of the conductor to its center, and in any event at high frequencies the distribution curve should lie between that of a solid conductor of the same overall diameter and applied voltage and that representing uniform distribution.

One simple embodiment of the invention is represented schematically in Figs. 2 and 2A. In the conductor there shown the strands are laid up in such manner that towards the center of the conductor the spacing between strands gradually increases. Insulating material may optionally be employed to maintain the strands in a more or less fixed space relation. Strips of insulating material may be inserted for this purpose or the stranding machine may be provided with means to coat the strands with insulating pulp as they are laid up into the central positions. A simple core of insulating material, string for example, may well be used instead of conducting strands, since it is current in the central conduct-

ing portion that is the most serious source of proximity effect.

Another embodiment of the invention comprises a conductor in which the strands travel more nearly longitudinally in their positions at the outside of the conductor and more nearly circumferentially or radially as the strands approach the center of the conductor. In cross-section, as shown in Fig. 3, the outer strands appear substantially circular, the central strands as elongated ellipses of substantially greater cross-section. Thus as each strand carries the same amount of current, the current per unit area is less in the center of the conductor than it is at the outside, and there is obtained an average current density that decreases toward the center of the conductor. Figs. 3A and 3B show the path traversed by a typical strand α .

Suitable physical positioning of the strands is not the only manner in which the present invention may be carried into practice. It is possible to have a uniform distribution of the strands and yet have a graduated current density. Specifically, such provision may be made that current traversing a central strand is permitted to leak off to adjacent less centrally located strands. Thus, some of the strands may be insulated and the others not insulated, as illustrated in Figs. 4 and 4A. The non-insulated strands may be tinned copper to promote the exchange of current between them. To insure good contact a silk or similar covering 2 may be wound tightly over the completed conductor.

In all of the embodiments of applicant's invention herein described it is desirable that over a given length of conductor each strand occupy for a certain distance every cross-sectional position that any other strand occupies. In such cases, all the strands are to be subjected to exactly the same electrical conditions and in exactly the same degree. Figs. 4 and 4A illustrate schematically a multiple-stranded conductor by which this requirement may be fulfilled. All of the strands that comprise the conductor are divided into groups of preferably three to five each, the strands of each group being then twisted together. The groups, in turn, are twisted together in larger groups of preferably three to five each; and the process thus continues until the conductor is built up to the desired diameter. If a larger number than five or six elements are twisted together in any one stranding operation a core of insulating material is preferably employed, the core being of sufficient diameter that all of the conducting elements lie in one layer.

The relative directions of twist in successive stranding operations and the relative lengths of twist are also to be considered. The least desirable arrangement is to have successive strandings in the same sense and of the same pitch, since in this case the strands do not change their radial positions at all. Changing the pitches but slightly is of little advantage since adjacent strands in different groups remain in close proximity to each other for too great a distance. Preferably successive stranding operations are in opposite senses, that is, if the strands are twisted together in a right-hand sense the groups should be twisted together in a left-hand sense. Preferably too the stranding pitch should increase with each successive operation in a ratio sufficient to equalize take-up throughout the conductor. This ratio is of the order of two in the case of the conductor shown in Figs. 4 and 4A.

Better meshing may result particularly with a

small number of strands, such as two or three, if there be employed different lengths of twist in the different units forming a group. As an example, if four groups of strands are laid together without twisting them the strands of one group will mesh perfectly with the strands of an adjacent group provided these groups have alternatively positive and negative twists of equal amount. If the four groups are twisted together the meshing will be perfect provided the difference in twists of the original groups is just taken up by twisting the four groups together.

Fig. 5 shows graphically how the effective resistance of several types of conductors varies qualitatively with respect to frequency. Curve A applies to a solid conductor, curve B to an ordinary stranded conductor and curve C to a conductor in accordance with applicant's invention. The maximum signaling frequency in a system of the type disclosed in applicant's patent, supra, would lie to the left of the junction of curves A and C.

It is to be understood that the embodiments of the invention herein disclosed are only illustrative and that the invention embraces all embodiments that come within the spirit and scope of the appended claim.

In the appended claim, the expression "average current density" refers to the current density averaged over a cross-sectional area of the stranded conductor, which includes insulation.

What is claimed is:

A high frequency transmission system including a stranded conductor carrying currents of super-audible frequency, said conductor comprising a multiplicity of reentrantly stranded filamentary wires, some of said wires being insulated and others uninsulated and corrosion-proof, and means binding said conductor to insure good electrical contact between said uninsulated wires at such points as they come in contact with each other, whereby there is leakage of current from each of said uninsulated wires at a point of contact with another of said uninsulated wires that is further removed from the center of the conductor at that point, the average current density in said conductor decreasing gradually from the periphery of said conductor inwards and the effective resistance of said conductor being less than it would be if all of said wires were insulated.

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