United States Patent

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[54] **RADIATING COAXIAL CABLE AND METHOD OF MANUFACTURE THEREOF**

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[52] **U.S. Cl.**.....**333/84 R,** 343/771, 29/600, 333/95 A, 333/96

[51] **Int. Cl.**.....**H01p 1/00,** H01p 11/00, H01q 13/22

[58] **Field of Search**.....343/770, 771, 905; 333/95 A, 333/96, 95 S

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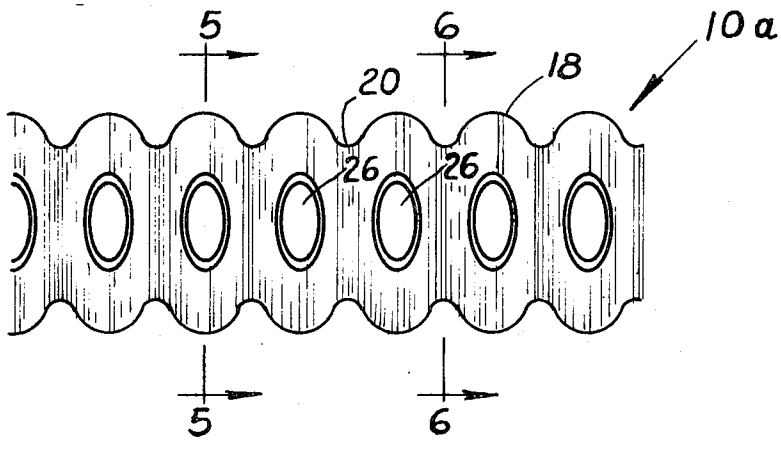
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[57] **ABSTRACT**

The crests of the corrugated outer conductor of a coaxial cable are partially removed along the length of one portion of its circumference to produce apertures in the corrugation crests while leaving the corrugation roots intact. The cable is thus made "leaky" for use as a radiator for tunnel communications systems and the like. Desirable aperture sizes and shapes are described.

12 Claims, 9 Drawing Figures



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SHEET 1 OF 2

Fig. 1

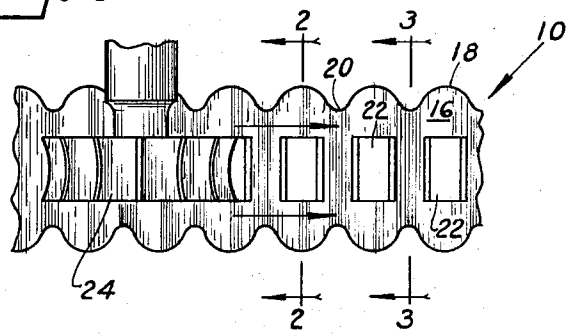


Fig. 2

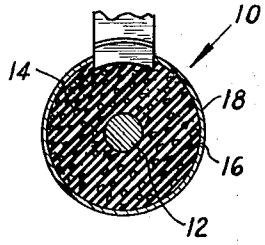


Fig. 3

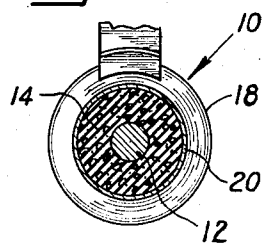


Fig. 4

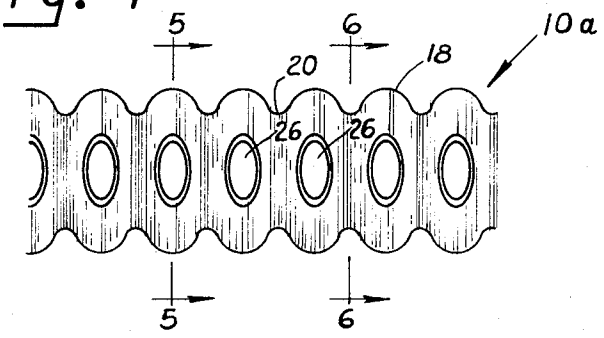


Fig. 5

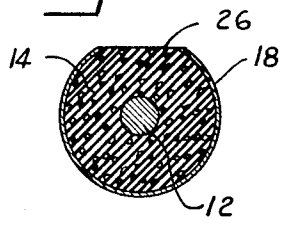
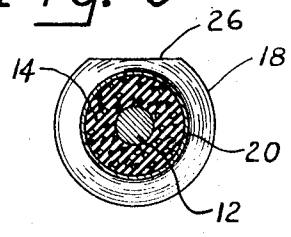


Fig. 6



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Fig. 7

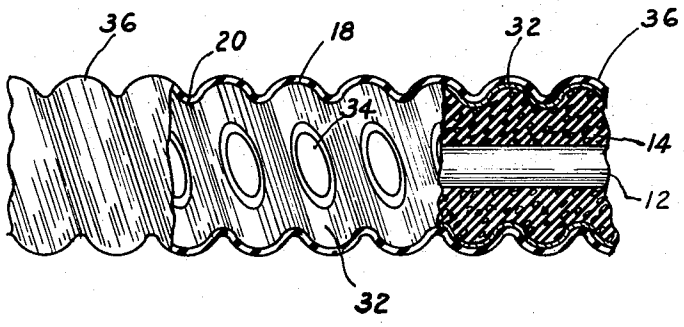


Fig. 8

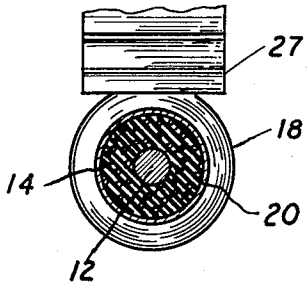
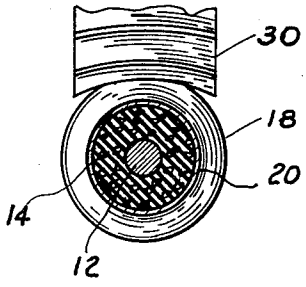


Fig. 9



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RADIATING COAXIAL CABLE AND METHOD OF MANUFACTURE THEREOF

This invention relates to high-frequency transmission elements of the type used for communications in tunnels and like purposes.

Various forms of long-length radiating high-frequency transmission elements have heretofore been proposed, and are in some cases now used, in the fixed-station portion of mobile radio communication systems designed to operate in tunnels, mines, and similar enclosures wherein ordinary fixed-station antenna radiators are impractical. Such long-length elements serve the combined functions of transmission lines and antennas. The simplest form of such an element is an ordinary open-wire transmission line, which inherently has substantial radiation loss. Coaxial lines and waveguides have also been employed, with conventional constructions modified by provision of special forms of apertures. Such apertured constructions, however, have heretofore been relatively complex and expensive to manufacture in order to obtain fully satisfactory electrical and mechanical characteristics. It is the principal object of this invention to provide a simple and easily fabricated long-length radiating transmission element of this general type.

The construction of the present invention is obtained by a manner of formation of the apertures which constitutes a simple and inexpensive addition to any known process of fabricating transmission elements of the type having a corrugated outer conductor. In the present invention, after fabrication of the corrugated tube, there is removed from the tube at least one angular sector of the corrugation crests, while leaving the corrugation roots intact, thus producing transverse radiating slots distributed along the entire length of the tube. The removal is most simply accomplished by a longitudinal milling operation, the corrugated tube being drawn past the milling tool.

As a further feature of the invention, the aperture dimensioning is correlated with the corrugation pitch or spacing in a manner which avoids necessity for precision of machining in order to produce electrical and mechanical uniformity despite the small variations in cable diameter, etc., which are encountered in economical manufacture. If the selected aperture size is too short in the longitudinal direction of the cable, preciseness of relative positioning of the tool and the tube is found highly critical to uniformity of size of the apertures produced. On the other hand, where it is sought to leave only the inner part of the root portion of the corrugation in the removal operation, excessive precision is required to avoid occasional complete severance of the corrugation root, thus essentially destroying the mechanical strength of the tube in any longitudinal region where this may occur. In accordance with this aspect of the invention, the crests are removed to a depth such that the longitudinal spacing between the slots or apertures is between one-half and twice the width (the dimension longitudinal of the tube). In this manner uniformity of electrical and mechanical characteristics is greatly improved for any given degree of precision of relative positioning of the tool and the tube.

These aspects of the invention, along with its further features and advantages, will be better understood by consideration of the exemplary embodiments thereof illustrated in the drawing, in which:

FIG. 1 is a fragmentary top plan view of a radiating high-frequency transmission element according to the broader aspects of the invention, also showing in more or less schematic form the method of its fabrication;

FIG. 2 is a transverse sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is a transverse sectional view taken along the line 3—3 of FIG. 1;

FIG. 4 is a fragmentary top plan view of another embodiment of the invention;

FIG. 5 is a transverse sectional view taken along the line 5—5 of FIG. 4;

FIG. 6 is a transverse sectional view taken along the line 6—6 of FIG. 4;

FIG. 7 is a plan view, partially in elevation and partially broken away in section, of a further embodiment of the invention;

FIG. 8 is a fragmentary view illustrating a step in the fabrication of the construction of FIG. 4 or 7; and

FIG. 9 illustrates a modification of the fabrication method shown in FIG. 8.

FIGS. 1 through 3 illustrate the invention in its broader basic aspects. A coaxial cable generally indicated at 10 has an inner conductor 12, a foam dielectric 14 and a corrugated outer conductor 16 having corrugation crests 18 and corrugation roots 20. The cable may be fabricated in any manner, but is preferably of the type produced by a continuous process of manufacture wherein a strip is continuously formed to the shape of a tube enclosing a foam-dielectric core. In the crests 18 are rectangular apertures 22. These are formed by a cutting operation in which the cable is moved past a milling cutter 24 which makes a cut of depth less than the root diameter of the cable, thus leaving the roots intact.

The improved embodiment of FIGS. 4 through 6 is generally similar but has a number of significant differences. Except for the apertures or slots and the manner of their formation, the cable 10*a* is of the same construction as that of FIGS. 1 through 3. The apertures of slots 26 are here of substantially different shape than the apertures or slots 22, being oval-shaped. The manner of formation of the oval-shaped slots is shown in FIG. 8, where it is seen that the apertures 26 are formed by a wholly planar cutting or removal operation, similar to the milling operation of FIGS. 1 through 3 but differing in that a planar cut made by the straight edge of cutter 27 extends entirely across a chord of the circular crest. The embodiment of FIGS. 4 through 6 has appreciable advantages over the rectangular-aperture embodiment of FIGS. 1 through 3. The transverse concavity of the rectangular aperture (best seen in FIG. 3) is eliminated, the sole deformation of the external circular shape being a flattened region (FIG. 6). When the illustrated apertures are enclosed within a protective plastic sheath (to be described in connection with FIG. 7), the construction of FIGS. 1 to 3 has sharp cutting edges which tend to tear through the sheath when the cable element is subjected to bending or abrasion. With the improved construction of FIGS. 4 through 6, however, the foam dielectric is substantially flush with the edges of the apertures and the sheath is backed by the foam in the region of the apertures, so that the installed sheath is radially supported everywhere.

A further advantage of the construction of FIGS. 4 through 6 lies in the relatively small loss of desirable mechanical properties for any given degree of radiation leakage permitted by the oval apertures 26 as compared with the rectangular apertures 22. The theory of radiation through such apertures, which are very small compared to a wavelength, is not yet thoroughly known. However, it is known that the amount of radiation which occurs is not merely a function of the area of the aperture, but varies with both the shape of the aperture and its orientation with respect to the polarization direction of the energy by which it is excited. The leakage efficiency from the oval apertures so formed may be shown to be substantially greater than from rectangular apertures of the same area formed by cutting tools to the same depth. Although the introduction of apertures of any shape necessarily introduces some degree of impairment of mechanical characteristics of a corrugated tube, for any specified amount of leakage radiation the loss of desirable mechanical characteristics of the corrugated tubing is substantially less with the oval-shaped apertures of FIG. 4 than with the rectangular apertures of FIG. 1.

A variant of the aperturing method of FIG. 8 is shown in FIG. 9. As there shown, the cutting-away of the corrugation crests 18 is performed with a concave milling cutter 30 in place of the linear-edged cutter 27 of FIG. 8. The transverse crest shape thus produced in the cutaway region is intermediate between the original circular arc and the planar flattening of FIG. 8. Such curvature produces, for any given central depth of cut, and thus for any given maximum width (in the direction of cable length) of slot, an oval-shaped slot of greater circumferential or angular extension. It is possible, of course, to increase the curvature of the cutting edge to the point where its radius of curvature reaches a semicircular arc matching the crest radius of the cable, but such concavity of the cutting tool is undesirable, as well as being unnecessary.

If so desired, there may be employed a plurality of sets of aligned apertures, although such an embodiment is not illustrated. Likewise, a single line of apertures may be formed with multiple cutting operations to extend the arc subtended, as by overlapping of cuts made in the manner of FIG. 8. The use of a curved cutting edge, or of such multiple cuts, is particularly desirable where high leakage radiation from small-diameter cable is wanted.

The embodiments thus far described have been shown as employing a cable having annular corrugations, for simplicity of illustration and understanding of the principles of the invention, although helical corrugations are in more common use. There is shown in FIG. 7 an embodiment manufactured by adding a cutting operation such as shown in FIG. 8 to a commercial cable manufacturing process wherein the cable is helically, rather than annularly, corrugated. In this embodiment, the helically corrugated outer conductor 32 has oval-shaped apertures 34 similar to those previously described. The shape symmetry of the oval of FIG. 4 is not lost by the longitudinal component of helical corrugation pitch of FIG. 7, the primary effect of the latter being very slight elongation of the oval with helix angles commonly used. The structure of FIG. 7 is encased in a plastic sheath 36, as previously mentioned. For efficiency of radiation, the sheath is constructed of a low-loss dielectric such as polyethylene, preferably omitting all high-loss additives such as those employed in the "black" polyethylene commonly employed in cable sheathing. Either relatively pure polyethylene or polyethylene with only low-loss additives (such as the brown polyethylene used for numerous outdoor applications) may be employed, having no substantial effect on the radiation in thicknesses fully sufficient for protective purposes.

Specific dimensional parameters of both the basic cable construction and the apertures may of course vary substantially, dependent upon the particular requirements of use. For use in typical two-way communication installations such as tunnels, subways, and mines, a corrugated cable of from approximately one-half inch to approximately 1 inch diameter is found suitable. In commercial coaxial cable, the corrugations are generally sinusoidal in form, as illustrated in the drawing. By forming the slots or apertures by cutting to a depth such that the bottom of the cut is in the regions of maximum radial slope of the corrugations, variations of slot dimensions due to variations of cutting depth are made small, and the normal variations of commercial cable diameter along the length are readily made to produce only small non-uniformities of aperture size.

Highly adequate signal strengths can be obtained along such "leaky" cable with only so small a portion of the crests cut away that the overall structure, after installation of the sheath, has substantially the same desirable mechanical characteristics as ordinary coaxial cable. The field intensity radiated varies somewhat with the frequency employed, with any given aperture size. Half-inch and seven-eighths inch radiating corrugating cables constructed in accordance with FIG. 7 have been tested at the commonly-used frequencies of 150 and 450 MHz over a substantial range of aperture sizes produced with a linear-edge milling cutter. With seven-eighths inch cables, cutting depths were used producing oval apertures of from 0.132 to 0.317 inch major axis. These leakage-aperture sizes correspond to a wide range of performance requirements for two-way communication systems with mobile transmitting and receiving units of varying receiver sensitivities and transmitter power. For communication with mobile units of high receiver sensitivity and high transmitter power, half-inch cables with oval apertures of 0.175 inch major axis can suffice, particularly in the higher frequency band. However, where substantially higher radiation is required, apertures of adequate size cannot in general be produced with a single planar cut in half-inch cable; in such case, fully adequate signal strength is obtained by intersecting planar cuts or by the employment of a concave milling cutter, to produce apertures of major axis corresponding to a chord-length of somewhat greater than 0.2 inch.

As is conventional in the art, the properties of the transmission element have herein been described in terms of "radiation," "leakage," etc. As in the case of prior devices for the same purpose, it will be understood that such terms describe the properties when the element is employed for reception of ambient signals as well as for radiation of signals fed to the cable in conventional fashion.

Persons skilled in the art will readily devise numerous embodiments of the method and product of the invention differing substantially from the embodiments herein described, but nevertheless utilizing the invention, particularly in its broader aspects. As one example, the broader teachings of the invention may be applied to corrugated waveguide excited in any mode wherein the direction of wall-current flow is longitudinal, i.e., similar to the coaxial cable transmission mode in this respect. As another example, gradation of aperture size may be produced along the length by mere adjustment of the cutting depth as the cable is moved past the cutting station; such gradation may be employed where the radiating cable is to be used in such long length, and with such requirement of uniformity of radiation, as to make it desirable to compensate for attenuation along the length.

The invention should accordingly not be considered limited by the particular embodiments illustrated and described, and the protection afforded thereto should extend to all utilization of the invention as defined in the claims below, and equivalents thereto.

What is claimed is:

1. A radiating high-frequency transmission element for tunnel communications and the like comprising an elongated transversely corrugated conducting tube having longitudinally aligned apertures in all corrugation crests, the corrugation roots being unapertured.

2. The radiating transmission element of claim 1 wherein the conducting tube is the outer conductor of a coaxial cable.

3. The radiating transmission element of claim 2 having a foam dielectric within the outer conductor.

4. The radiating transmission element of claim 1 having a low-loss dielectric sheath encasing the corrugated tube.

5. The radiating transmission element of claim 1 having the apertures of generally oval shape.

6. The radiating transmission element of claim 1 comprising a corrugated generally circular tube having at least one portion of the circular periphery thereof cut away from circularity along its entire length to form the apertures.

7. The transmission element of claim 6 wherein the transverse shape is free of concavities.

8. The transmission element of claim 6 wherein the apertures are of a width from one-half to twice the distance of the spacing therebetween.

9. The radiating high-frequency transmission element of claim 1 comprising a corrugated foam-dielectric coaxial cable having generally oval-shape apertures in the corrugation crests and enclosed in a low-loss dielectric sheath.

10. In a method of making a radiating high-frequency transmission element for tunnel communications and the like, the improvement comprising removing at least one angular sector of all the corrugation crests of a corrugated high-frequency transmission element while leaving the corrugation roots intact.

11. The improved method of claim 10 wherein the transmission element is substantially circular and said sector of the corrugation crests is removed by cutting away a circumferential portion leaving the transverse shape free of concavity.

12. The improved method of claim 10 including the added step of thereafter encasing the element in a low-loss dielectric sheath.

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