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M. E. HINES ET AL
MULTICOAXIAL LINE CABLES

2,997,519

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2 Sheets-Sheet 1

FIG. 1

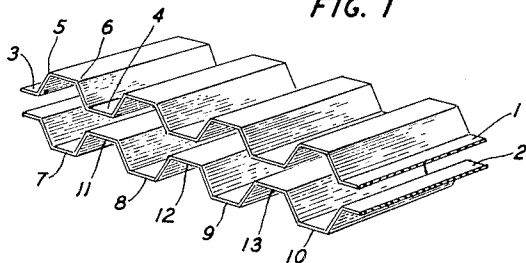


FIG. 2

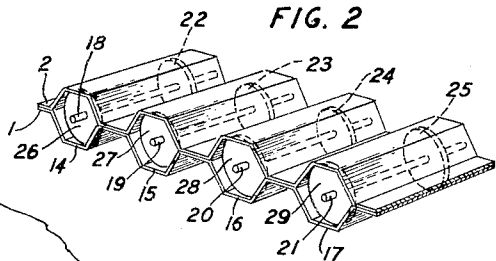


FIG. 3

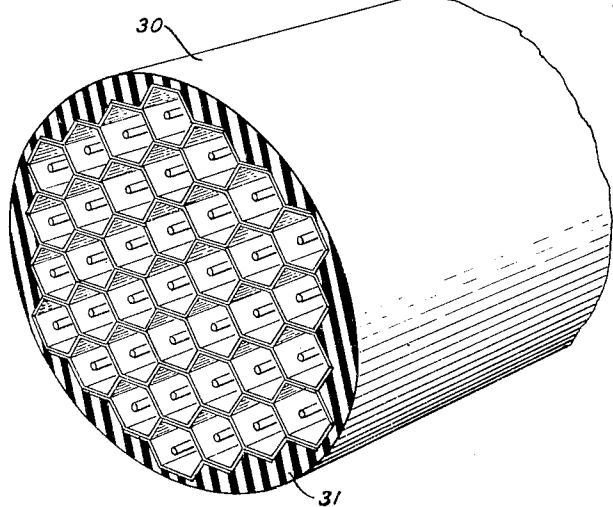
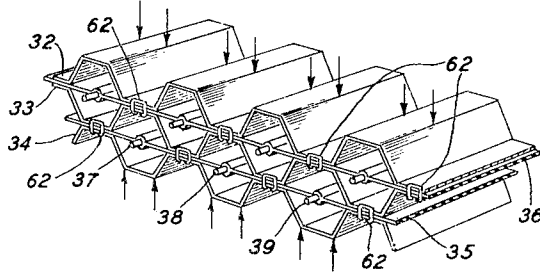


FIG. 4



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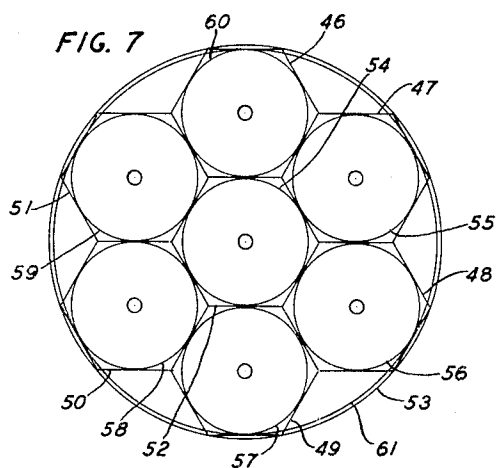
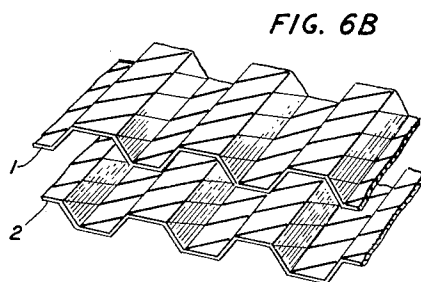
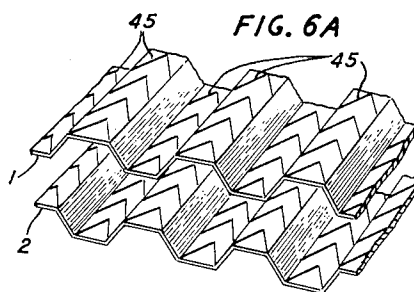
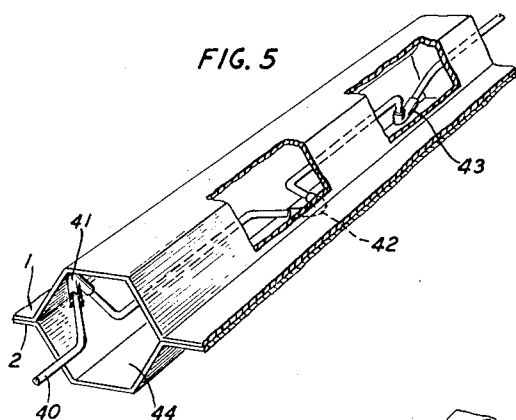
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2 Sheets-Sheet 2



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MULTICOAXIAL LINE CABLES

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9 Claims. (Cl. 174-28)

This invention deals with electric cables for high-frequency transmission and more particularly with cables comprising a plurality of coaxial lines.

Foreseeable abrupt increases in the employment of high-frequency pulse systems, for data transmission and the like, have focused attention on the need for cables comprising coaxial lines that may be produced both efficiently and economically. With known methods and structure the cost of producing coaxial cables is a factor which in many instances tends to limit their use. Each individual coaxial line must be fabricated as a separate operation. Additionally, the operation of combining the individual lines into a single cable, which is both costly and time consuming, subjects the lines to stresses which tend to reduce the uniformity of both their electrical and mechanical characteristics. A further disadvantage of prior art structures is that the employment of cylindrical outer conductors results in the formation of open spaces between such conductors when they are packed together in cable form. Pressure on the outside of the cable tends to force the individual cylindrical members into the open spaces which is conducive to mechanical deformation and attendant variations in transmission characteristics.

A general object of the invention, therefore, is to provide an improved multicoaxial line cable that can be produced both economically and efficiently.

A more specific object of the invention is to provide a multicoaxial line cable that positively limits relative movement between individual lines in the cable while still retaining a high degree of flexibility in the cable as a whole.

A further object of the invention is to provide means by which the center conductors of a plurality of coaxial lines comprising a cable may be positioned within their respective outer conductors by a single operation.

An additional object of the invention is to provide a multicoaxial line cable which is characterized by an optimum combination of both physical and electrical properties.

The principles of the invention are based in part on the realization that the configuration of the outer conductor of a coaxial line may be changed substantially from its conventional cylindrical form with little, if any, impairment of its electrical properties and with a marked improvement in its mechanical properties. Specifically, the principles of the invention contemplate the employment of a hexagonal form for the outer conductor of each of the coaxial lines in a multicoaxial line cable. With the employment of outer conductors which are hexagonal in cross section, it is apparent that a number of coaxial lines may be closely and securely packed together after the fashion of the classical honeycomb configuration.

The invention uniquely turns to account the employment of closely packed hexagonal outer conductors in still another way. In the construction of a cable, in accordance with the principles of the invention, the outer conductors are formed by a plurality of conductive strips each of which is equal in length to the desired length of the cable or cable section. Each of the strips is bent along its length to form a plurality of parallel, adjacent, longitudinal, three-sided, half-hexagonal channels or grooves which are successively open on opposite sides of the strip. Two of such strips placed in the proper juxta-

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posed relation form a single row of coaxial cable outer conductors, each hexagonal in cross section. By stacking additional strips together with the two strips described, the number of outer conductors in the cable may be increased as desired and the over-all cross section of the cable so formed is a plurality of closely packed hexagons or a so-called honeycomb array. It is evident then that according to the principles of the invention, a plurality of coaxial line outer conductors may be fabricated and assembled in a single step, that is by stacking together appropriately bent strips, in contrast to the multiple operations required heretofore. Moreover, since each of the hexagonal outer conductors is mechanically discontinuous, although electrically continuous, ready access is provided for the positioning of inner conductors, either by conventional means or in accordance with a particular aspect of the invention.

In one illustrative embodiment of the invention a cable comprising a bundle of hexagonal coaxial lines with outer conductors assembled as described is bound together by a covering of insulation. Since both edges of each of the outer conductor strips abut the insulating covering, lateral movement between individual coaxial lines is prohibited.

Various arrangements are employed in the prior art to increase the flexibility of coaxial cable. For example, some cables employ outer conductors comprising helically wound copper strips and others employ outer conductors which are corrugated. One aspect of the instant invention is the employment of corrugations on the outer conductors of each of a plurality of coaxial lines in a cable with the corrugations so formed that they impart a good degree of flexibility to the cable and at the same time interlock with adjacent outer conductors so as to prohibit longitudinal movement between adjacent conductors, or more precisely between adjacent outer conductor strips.

In an array of outer conductors which conform in structure to the principles of the invention, the inner conductors may be positioned by conventional means, as suggested above. For example, each individual inner conductor may be threaded through its respective outer conductor and retained in spaced relation thereto by means of insulating beads or washers. In accordance with a further principle of the invention, however, all of the inner conductors corresponding to all of the outer conductors which are formed by two adjacent channeled strips may be positioned in a single operation by turning to account the mechanical or structural discontinuity of each of the outer conductors. Before the two conductive strips which comprise a single row of outer conductors are placed in juxtaposition, a relatively thin strip of suitable insulating material, which is comparable in length and width to the conductive strips, is placed in juxtaposition with one of the conductive strips. A number of inner conductors are suitably affixed longitudinally on the insulating strip, each being placed in such a position that it is concentrically aligned with its respective outer conductor. Hence, the positioning of a plurality of inner conductors may be effected readily in a single operation.

One feature of the invention, therefore, is a honeycomb bundle of coaxial lines with outer conductors formed from a plurality of suitably bent or channeled strips of conductive material placed in juxtaposition.

A further feature of the invention is a means for positioning a plurality of inner conductors in a bundle of hexagonal coaxial conductors constructed as described, comprising an insulating strip to which the inner conductors have been suitably affixed.

A still further feature of the invention is the employment of interlocking corrugated surfaces on the juxta-

posed sides of all the hexagonal outer conductors which form a honeycomb bundle of coaxial lines.

The invention, together with additional objects and features thereof, will be fully apprehended from a consideration of the following detailed description and accompanying drawings of particular embodiments, in which:

FIG. 1 is a sketch of two longitudinally bent strips designed, in accordance with the invention, to form the outer conductors of a plurality of coaxial lines;

FIG. 2 is a sketch of the strips of FIG. 1 placed in juxtaposition with an inner conductor conventionally positioned in each outer conductor;

FIG. 3 is a cross section view, in perspective, of a cable comprising a plurality of hexagonal coaxial lines;

FIG. 4 is a cross section view, in perspective, of a cable which employs insulating strips to position the inner conductors of a plurality of hexagonal coaxial lines;

FIG. 5 is a cross section view, in perspective, of a single hexagonal coaxial line in which kinks of the inner conductor are employed to retain it in place;

FIG. 6A is a sketch of the outer conductor strips shown in FIG. 1 with corrugations in each of the horizontal surfaces; FIG. 6B is a sketch of the outer conductor strips shown in FIG. 1 with corrugations in both the horizontal and slant faces of the strips; and

FIG. 7 is a cross section view of a cable, in accordance with the invention, with cylindrical conductors shown; for comparison purposes, inscribed in the several hexagonal outer conductors.

One of the more significant aspects of the invention, the use of conducting strips to form hexagonal outer conductors, is illustrated in FIG. 1. The pair of electrically conducting strips 1 and 2 have each been formed into a plurality of parallel, longitudinal, three-sided grooves or channels by a succession of 60 degree longitudinal bends. Each of the channels is formed by a group of four successive bends, and in each group the first and fourth bends, such as 3 and 4, are made in a first direction, and the second and third bends, such as 5 and 6, are made in a second direction opposite to the first. The material of the strips is normally metallic and may advantageously be of copper, for example. The bending operations may be effected by any one of a number of means known in the metal working art, as by stamping, or by drawing the metal over an array of suitably formed rollers, for example.

The strips, formed in accordance with the invention as indicated above, may be viewed as a plurality of channels, such as 7, 8, 9, and 10, equal in dimension, and equally spaced or, stated otherwise, the strips comprise a series of adjacent channels of equal dimension with alternate ones 7, 8, 9, and 10 open on one side of the strip and intermediate ones 11, 12, and 13 open on the opposite side of the strip. The principles of the invention contemplate the employment of each of the oppositely facing adjacent channels as one half of the outer conductor of a coaxial line. This employment of the strips is shown in FIG. 2.

In FIG. 2 the two strips 1 and 2, also shown in FIG. 1, have been placed together so that each channel in each strip is in juxtaposition with an oppositely facing channel in the other strip so that a row of spaced outer conductors 14, 15, 16, and 17 is formed, each hexagonal in cross section. Four inner conductors 18, 19, 20, and 21 are also shown, each placed concentrically in a respective one of the outer conductors. Each inner conductor 18, 19, 20, and 21 is fixed, conventionally, in the center of its respective outer conductor 14, 15, 16, and 17 by spacers or washers 22 through 29 which may be of insulating material such as hard rubber or polyethylene, for example. Alternatively, a solid dielectric such as polyethylene or a suitable foamed insulating material may be employed.

FIG. 3 shows an entire cable 30 comprising a total of 37 coaxial lines which in structure and in method of

assembly conform to the principles of the invention. A total of 14 electrically conductive strips have been stacked together in the manner illustrated in FIGS. 1 and 2 to form the substantially cylindrical honeycomb bundle of coaxial lines. The outer periphery of a honeycomb bundle of coaxial lines embodying the principles of the invention may of course be adjusted to any desired form by varying the number and relative positions of the individual lines. In FIG. 3 the proper concentric positioning of each of the center conductors is attained by the use of a solid dielectric, such as polyethylene, which in some instances may be more advantageous than the use of washers, beads or spacers as shown in FIG. 2.

In any complete cable structure it is usual to employ an outer covering or shield to promote both mechanical strength and electrical isolation. In FIG. 3, the outer covering 31, which may be of lead, for example, is substantially cylindrical on its outer surface while its inner surface is of an irregular form so that it fills in the spaces around the outer edge of the honeycomb bundle. Alternatively, of course, the outer surface of the outer covering 31 may be made to conform to the outer surfaces of the honeycomb bundle.

FIG. 4 illustrates a particular feature of the invention which is a unique means for positioning the inner conductors in a cable constructed in accordance with the principles of the invention. Three outer conductor strips 32, 33, and 34 are shown stacked together, in the same fashion illustrated by FIGS. 1 and 2, and relatively thin flat strips of insulating material 35 and 36, such as polyethylene for example, have been placed between the contacting horizontal surfaces of the adjacent bent strips 32 and 33, and 33 and 34, respectively. Along the length of each of the insulating strips the inner conductors, for example 37, 38, and 39, have been embedded or otherwise affixed at the proper intervals. Stretching the insulating strips 35 and 36 before they are locked in place by the pressure of the adjacent conducting strips 32, 33, and 34 ensures the elimination of any sag in the insulating strips which in turn ensures that each of the inner conductors is accurately positioned concentrically with relation to its respective outer conductor.

Any one of a number of means may be employed to ensure electrical continuity between the two halves of each outer conductor which would otherwise be insulatedly separated by the strips 35 and 36. For example, conductive staples 62 may be used, as shown, or, alternatively, conductive particles may be suitably embedded in the insulating strips 35 and 36 to provide a conductive path between adjacent outer conductor strips. Another method of ensuring electrical continuity between the two halves of each outer conductor is the employment of insulating strips with suitable gaps at points where contact between adjacent conductive strips is desired. Still another method is the employment of transverse strips spaced sufficiently far apart to ensure contact between adjacent conductive strips.

In accordance with the invention an additional means may be employed to ensure accurate positioning of the inner conductors. Each of the bends in the outer conductor strips may be made at an angle slightly greater than that required to produce the half-hexagonal channels shown in the drawings. The resulting hexagonal outer conductors are thus slightly elongated on the axes perpendicular to the insulating inner conductor strips. In the process of assembly, pressure is applied to the strips, as indicated by the arrows in FIG. 4, and each hexagon is compressed slightly in a direction perpendicular to the insulating strips and expanded slightly in a direction parallel to the insulating strips until each interior angle of each hexagonal outer conductor measures 60 degrees. It is apparent that such action serves to stretch each insulating strip transversely across the interior of each outer conductor, thus giving somewhat

greater accuracy to the concentric positioning of each inner conductor in its respective outer conductor.

FIG. 5 illustrates an alternative method of supporting the inner conductor in a coaxial line constructed in accordance with the principles of the invention. As in FIG. 2, two electrically conductive strips 1 and 2, each suitably bent to form a half-hexagonal channel, have been placed in juxtaposition to form a hexagonal outer conductor 44. The center conductor 40 has been bent or kinked sharply at suitable intervals 41, 42, and 43, and each kink is wedged into a respective one of the angles formed by adjacent sides of the outer conductor 44. Shifting the point of contact between the inner and outer conductor by 120 degrees at each successive kink of the inner conductor ensures uniform support for the inner conductor throughout the length of the line. The inner conductor 40 is, of course, insulated from the outer conductor 44 at each of the kinks 41, 42, and 43, which may be achieved by a small section of insulation at the appropriate points on the inner conductor as shown, or by insulating a small spot at each contact point on the interior of the inner conductor. Changes in transmission properties resulting from the kinked inner conductor, as compared to a straight conductor, are relatively minor and can be readily compensated for.

While it is apparent that a honeycomb arrangement of closely packed hexagons, as shown for example in FIG. 3, precludes relative lateral movement between adjacent conducting strips, since the edges of each strip are wedged against the outer covering 31, the arrangement does not afford similar resistance to relative longitudinal movement between adjacent conducting strips. Such relative movement is to be avoided, just as lateral movement, since repeated longitudinal shifting of the conducting strips with respect to one another may have an adverse effect on both the electrical and the mechanical properties of the cable. In the prior art, one method which is employed to avoid relative movement among the individual cylindrical coaxial lines in a cable is to twist the lines in spiral fashion. This method is objectionable, however, since the flexibility of the cable is decreased thereby and the lines are subjected to mechanical stresses by the twisting process which is conducive to the introduction of variations in the transmission characteristics of the lines.

In accordance with the principles of the invention, this problem is met in the manner illustrated in FIG. 6A and FIG. 6B. FIG. 6A shows a pair of outer conductor strips 1 and 2 similar to the strips shown in FIG. 1. In FIG. 6A, however, each of the horizontal faces of each of the strips has been impressed with corrugations so that when two corrugated surfaces are placed together they will interlock, thereby preventing relative longitudinal displacement between adjacent conducting strips 1 and 2. The corrugations may of course take any one of a variety of forms, such as sawtooth or sinusoidal for example, and still perform the function for which they are intended. It would appear that the corrugations in the surfaces of the outer conductor would produce impedance discontinuities. Such discontinuities may readily be avoided, however, by positioning successive indentations at intervals of less than one-quarter wavelength at the highest operating frequency on the line. Additionally, indentations on the top and bottom plane of an outer conductor may be offset with respect to each other which reduces still further the possibility of creating impedance discontinuities.

The interlocking feature of the corrugations is effective even when the indentations are very shallow and thus changes in the transmission characteristics of the line may be held to a minimum. Moreover, since the corrugations are uniform, changes in electrical properties brought about by the convex corrugations, such as increased capacitance, for example, are eliminated, or at least substantially reduced, by the matching concave cor-

rugations. In addition to the function of preventing relative movement between adjacent conducting strips, corrugations increase the flexibility of each individual coaxial line and thereby increase the flexibility of the cable as a whole. In applications where maximum cable flexibility is a desirable feature, corrugations may be impressed on every face of the outer conductor strips, as shown in FIG. 6B, instead of restricting the corrugations to the horizontal surfaces as shown in FIG. 6A. When corrugations are impressed on all surfaces of the outer conductors, as shown in FIG. 6B, the indentations not only provide predetermined points at which each coaxial line may flex, but also they serve the function of providing additional conductor length for a given length of transmission line so that the conductors on the outside of a bend may stretch, thereby avoiding any sharp buckling.

It is of course recognized that the cylindrical configuration is in some respects ideal for the outer conductor of a coaxial line since for a particular attenuation per unit length, the actual volume enclosed by a cylindrical conductor is less than for other configurations. While this advantage is clear for a single coaxial line, it tends to disappear when the physical size and transmission characteristics of a cable comprising a plurality of coaxial lines with cylindrical outer conductors are compared to those properties in a cable employing coaxial lines constructed in accordance with the invention. Such a comparison is best illustrated in FIG. 7. A total of seven closely packed hexagonal outer conductors 46 through 52 are shown encased in an outer covering 53. For comparison purposes each one of seven cylindrical conductors 54 through 60 is inscribed in a respective one of the hexagonal conductors 46 through 52. It may be observed that the total volume, or cross sectional area formed by enclosing the hexagonal conductors in the cylindrical outer covering 53, represents only a very insignificant increase over the total volume or cross sectional area formed by enclosing the cylindrical conductors in the cylindrical outer covering 61. Moreover, in addition to the desirable mechanical features, as described above, which are afforded by a honeycomb bundle of coaxial lines, the hexagonal conductors 46 through 52 have preferred transmission characteristics over the inscribed cylindrical conductors 54 through 60. Specifically, the capacitance of the hexagonal conductors is less since the average distance of the sides of each of the hexagonal conductors from its respective center conductor is of course greater than the distance of each cylindrical conductor from its respective inner conductor. Consequently, it may be observed that the features of the invention, when embodied in a cable comprising a plurality of coaxial lines, provide not only structural advantages but also advantages in transmission characteristics.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of this invention. Numerous other arrangements may be designed by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A transmission cable including a plurality of coaxial lines each comprising an inner and an outer conductor, said outer conductors comprising a plurality of electrically conductive strips each bent successively to form a plurality of open, longitudinal, parallel, half-hexagonal channels, alternate ones of said channels being open on one side of said strip and intervening ones of said channels being open on the opposite side of said strip, means positioning said strips in juxtaposition thereby to form a closely-packed honeycomb bundle of said outer conductors, each of said outer conductors being hexagonal in cross section, and means positioning each of said inner conductors in a respective one of said outer conductors.

2. Apparatus in accordance with claim 1 wherein said inner conductor positioning means comprises a plurality of strips of insulating material, each of said insulating

strips being stretched between and secured by a respective adjacent pair of said electrically conductive strips, and means affixing the inner conductors of each of said groups of outer conductors to a respective one of said insulating strips.

3. A transmission cable including a plurality of groups of coaxial lines, each line comprising a cylindrical inner conductor and a hexagonal outer conductor, each of said groups of outer conductors comprising a pair of juxtaposed electrically conductive strips each formed into a plurality of successively oppositely facing, open, half-hexagonal channels, means positioning each of said pairs of conductive strips in juxtaposition thereby to form a closely-packed honeycomb bundle of said hexagonal outer conductors, means interlocking each of said conductive strips to the conductive strips adjacent thereto, and means positioning each of said inner conductors in a respective one of said outer conductors.

4. Apparatus in accordance with claim 3 wherein said interlocking means comprises corrugations on each of the surfaces on each of said conductive strips which is in juxtaposed relation with a surface on conductive strips adjacent thereto.

5. A transmission cable including a plurality of groups of coaxial lines, each line comprising a cylindrical inner conductor and a hexagonal outer conductor, each of said groups of outer conductors comprising a pair of juxtaposed electrically conductive strips each formed into a plurality of successively oppositely facing, open, half-hexagonal channels, means positioning each of said pairs of conductive strips in juxtaposition thereby to form a closely-packed honeycomb bundle of said hexagonal outer conductors, means ensuring a preselected degree of flexibility in said cable, said flexibility ensuring means interlocking each of said conductive strips to the conductive strips adjacent thereto, and means positioning each of said inner conductors in a respective one of said outer conductors.

6. Apparatus in accordance with claim 5 wherein said

flexibility ensuring means comprises corrugations on all surfaces of said conductive strips.

7. Apparatus in accordance with claim 6 wherein said inner conductor positioning means comprises a plurality of substantially flat, insulating strips each stretched between and secured by a respective adjacent pair of said conductive strips, and means affixing the inner conductors of each of said groups to a respective one of said insulating strips.

8. Apparatus in accordance with claim 6 wherein said affixing means comprises means for embedding said inner conductors in said insulating strips.

9. A plurality of outer conductors for a coaxial cable comprising a plurality of electrically conductive strips each including a plurality of parallel, longitudinal, half-hexagonal channels, each of said strips being placed in juxtaposition with at least one other of said strips with complementary ones of said half-hexagonal channels in correspondence, whereby each of said plurality of outer conductors formed thereby is hexagonal in cross section, each comprising one of said half-hexagonal channels from one of said strips and one of said half-hexagonal channels from another of said strips.

References Cited in the file of this patent

UNITED STATES PATENTS

334,850	Denison	Jan. 26, 1886
730,251	Gibbs	June 9, 1903
1,132,676	Murray et al.	Mar. 23, 1915
2,034,036	Green	Mar. 17, 1936
2,223,116	Meyer	Nov. 26, 1940
2,614,172	Greenfield	Oct. 14, 1952
2,636,923	Perzel	Apr. 28, 1953
2,796,589	Adams	June 18, 1957
2,952,728	Yokose	Sept. 13, 1960

FOREIGN PATENTS

686,998	Germany	Jan. 20, 1940
952,417	France	May 2, 1949