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S. W. MOULTON
ANTENNA STRUCTURE UNFURLABLE FROM RIBBON FORM
INTO TUBULAR SHAPE

3,331,075

Filed July 6, 1965

3 Sheets-Sheet 1

Fig. 1.

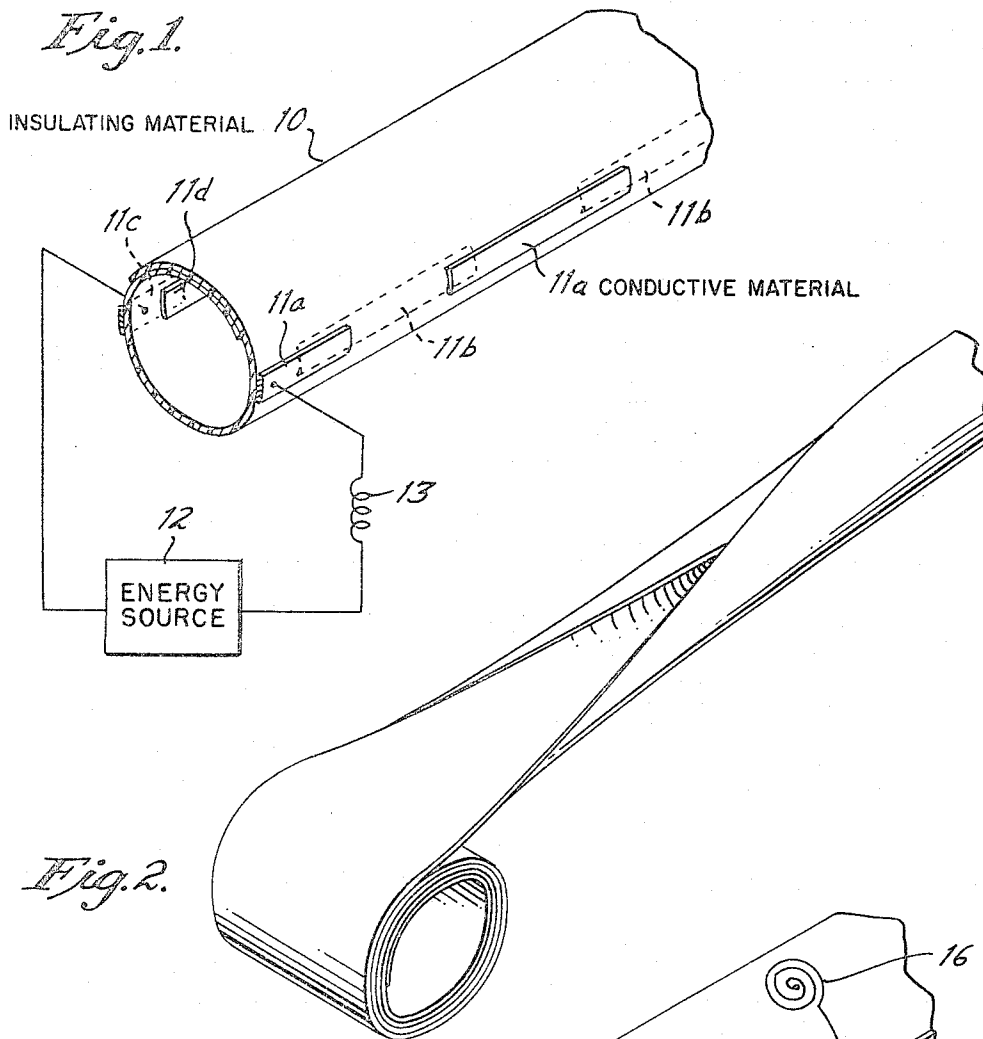


Fig. 2.

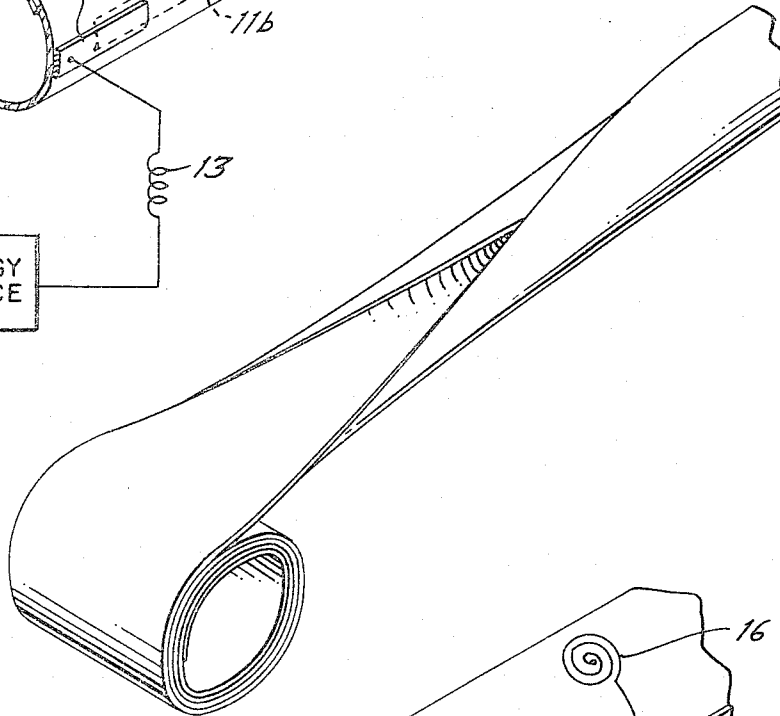
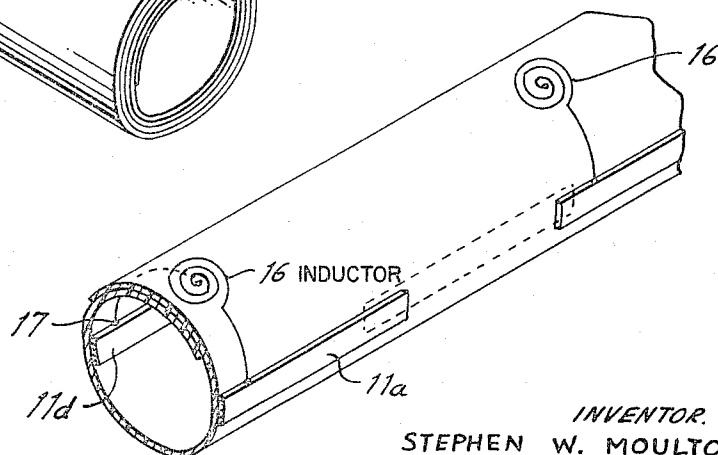


Fig. 3.



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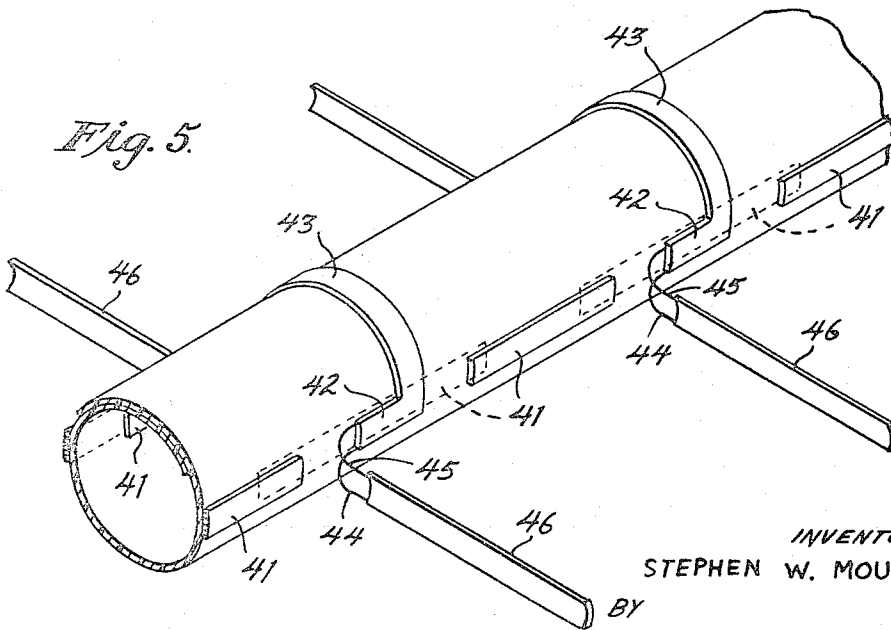
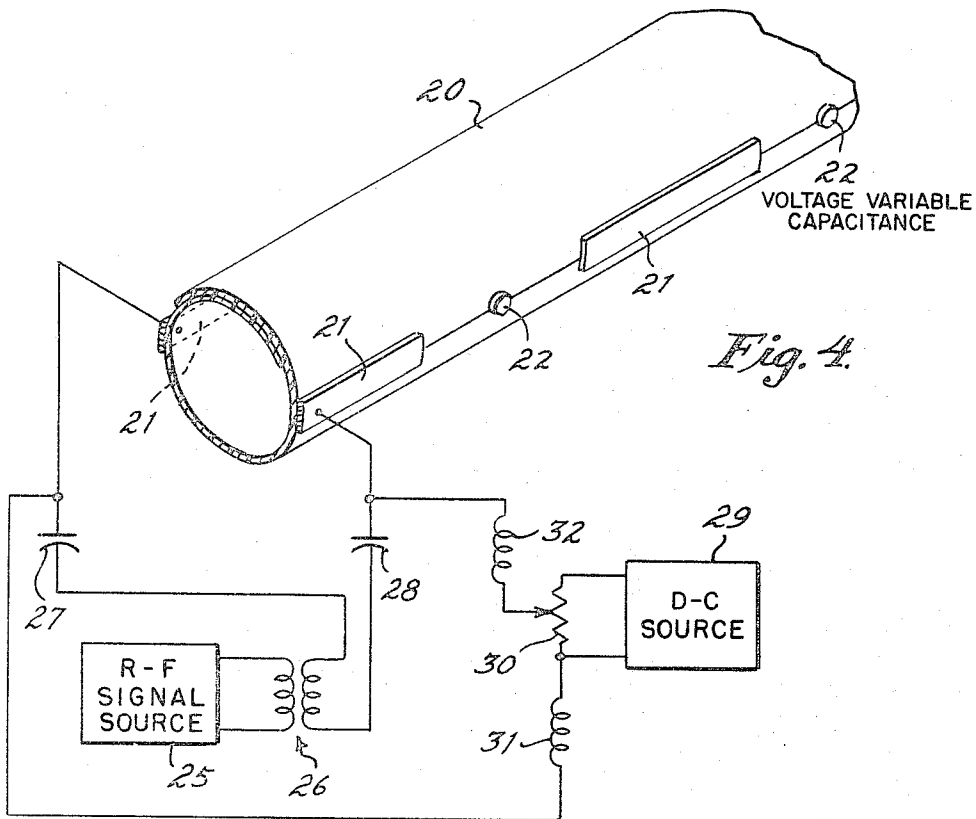
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5 Sheets-Sheet 2



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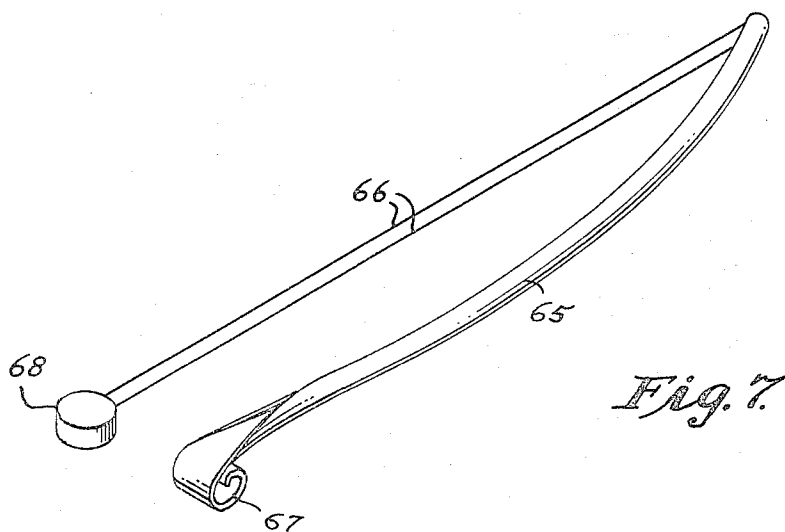
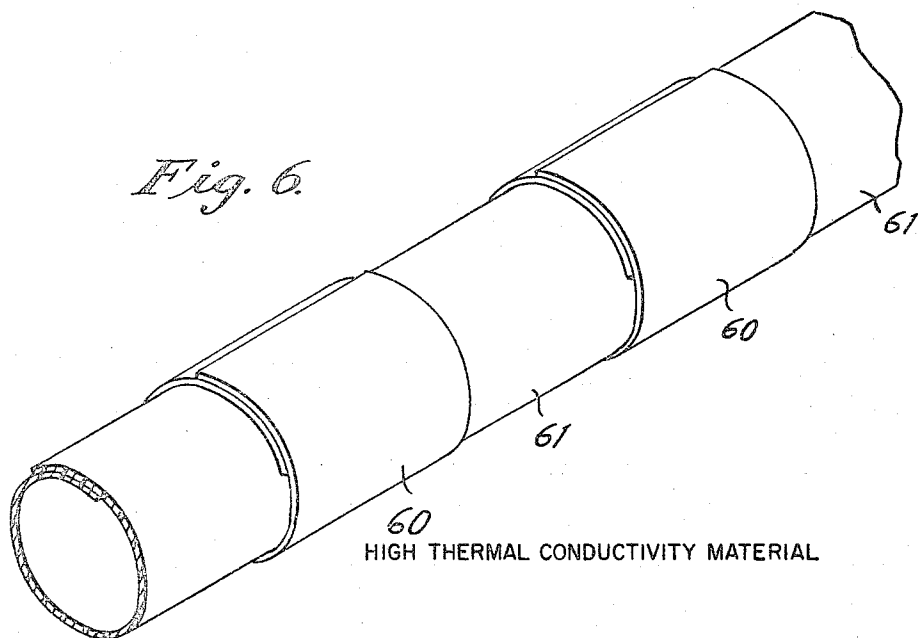
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ANTENNA STRUCTURE UNFURLABLE FROM RIBBON FORM INTO TUBULAR SHAPE

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22 Claims. (Cl. 343—814)

This invention relates to antennas and to extendable support structures for antennas.

Recent advances in technology have imposed many new and severe requirements on antennas for radiating and receiving electromagnetic energy. In particular, space technology has given rise to increasingly stringent requirements with respect to the physical parameters of size, weight, etc., of antennas, as well as with respect to their electrical parameters of directivity, bandwidth, etc., and the relationships between these various parameters.

For example, an antenna to be mounted in an earth satellite for communication with a station on earth may have to meet simultaneously all of the following requirements: high directivity, stable directivity, wide bandwidth, low weight, small size at launch, high resistance to the space environment, and many others.

Generally speaking, desirable electrical antenna characteristics go hand-in-hand with considerable antenna size which, however, is inimical to the equally critical mechanical requirements of small size at launch and low weight.

To reconcile these conflicting requirements, it has been proposed to build antennas in extendable form. These would be packaged into a small space for launching and would then be extended to the desired size in the space environment, where smallness of size is not as important. To keep the weight down, it has further been proposed to make the antennas hollow, so that only the weight of the outer wall plus any extending mechanism would have to be accommodated.

The physical form proposed for such antennas is a hollow metal tube or cylinder, with longitudinal edge portions which overlap, but without being permanently attached to one another. The tube is so dimensioned that it can be spread open into a flat metal ribbon and, in this ribbon form, wound up into a spool. When unwound from the spool, the ribbon, due to transverse stresses built into it, again curls up into the desired tube with overlapping longitudinal edge portions.

Such antenna structures, together with apparatus for winding and unwinding them, are described and illustrated in a paper by John W. MacNaughton entitled, "Unfurlable Metal Structures for Spacecraft," presented to the Astronautics Symposium of the Canadian Aeronautics and Space Institute, March 1963.

These proposed antennas still left much to be desired, with respect to mechanical properties, electrical properties, and the relationships therebetween.

Accordingly, it is a primary object of this invention to provide improved antennas free from some of the shortcomings of the prior art.

It is another object to provide antenna structures which have improved mechanical properties.

It is still another object to provide antenna structures which have improved electrical properties.

It is a still further object to provide antenna structures having improved relationships between mechanical and electrical properties.

It is yet another object to provide improved support structures for antennas.

These and other objects which will appear are achieved in accordance with this invention by means of an elon-

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gated ribbon of material having low electrical conductivity and so prestressed as to curl up into a tube with overlapping longitudinal edge portions when unwound from a spool formed of the ribbon.

The ribbon is preferably made of fiberglass. Carried by the ribbon are the electrically active portions of the antenna which are supported in their desired physical antenna configuration by the tube when the latter has been formed through unwinding of the ribbon spool.

It is a feature of this invention that the electrically active antenna portions may be in the form of a so-called fast wave structure, which is characterized in that electrical waves propagate along the structure at a phase velocity greater than the velocity of light.

For further details reference may be had to the description which follows and the accompanying illustrative drawings wherein:

FIGURE 1 shows a segment of an antenna structure in accordance with this invention, together with ancillary apparatus involved in the operation of the structure as an antenna;

FIGURE 2 is a diagrammatical illustration of the manner in which a structure such as shown in FIGURE 1 may be given the tubular form exhibit in FIGURE 2;

FIGURE 3 shows a segment of another antenna structure in accordance with the invention;

FIGURE 4 shows an antenna arrangement according to the invention in which the radiating pattern can be controlled electrically;

FIGURE 5 shows an antenna structure according to the invention which is especially suited for operating with one type of polarization;

FIGURE 6 shows another form of antenna structure according to the invention; and

FIGURE 7 shows still another such form.

The same reference numerals designated similar parts in different figures. In many instances the dimensions of the apparatus shown have been exaggerated, or otherwise distorted, in order to provide greater clarity of illustration.

The antenna structure of FIG. 1, to which reference may now be had, comprises a tube 10, having longitudinal edges which overlap as shown. Tube 10 is made of an insulating material, preferably fiberglass. For reasons discussed later, this fiberglass is preferably oriented with its fibers aligned principally parallel to the tube axis. It will be understood that the wall of this tube may, in practice, be thinner than shown in FIGURE 1. For a tube of one inch diameter, the wall thickness may, for example, be as low as about 10 mils.

Applied to the surface of tube 10 are segments 11 of electrically conductive material. These segments may be made of copper which may be plated directly onto tube 10.

As shown in FIG. 1, there are four sets of segments 11. One set (11a) is applied to the outside of the tube on the side nearest the viewer in FIG. 1. Another set (11b), shown in broken lines in FIG. 1, is applied to the inside of the tube. The segments of set 11b are applied at the same peripheral position on the tube as those set 11a and partially overlap successive segments of the latter set. Set 11c, of which only part of one element is shown (also in broken lines) in FIG. 1, is applied to the outside of tube 10 diametrically opposite set 11a. Set 11d, of which again only part of one element appears in FIG. 1, is applied to the inside of the tube, diametrically opposite set 11b.

It will be understood that what is shown in FIG. 1 is only a portion of tube 10, specifically, that portion to which are applied the last few of segments 11. These conductive segments 11, arranged in sets as described above,

will usually extend substantially the full length of tube 10.

For storage purposes the fiberglass ribbon of which tube 10 of FIG. 1 is constituted, may be flattened out and in its flattened-out state rolled up into a spool. When unrolled, it again forms a tube. The transition between spool and tube is diagrammatically illustrated in FIG. 2.

Referring again to FIG. 1, it will be understood that each pair of sets of conductive elements at the same peripheral position on tube 10 constitutes in effect a conductor extending longitudinally of the tube and interrupted at the extremity of each element by a series capacitor formed by the portion of the insulating wall of tube 10 which separates an external segment from the overlapping portion of the adjacent internal segment.

Thus in FIG. 1 there are in effect two parallel conductors interrupted by series capacitors and spaced apart by the diameter of tube 10. These serve as the electrically active elements of the antenna.

A conventional source 12 of the electromagnetic energy which it is desired to radiate by means of the structure of FIG. 1 may be connected via an appropriate matching impedance 13 to the ends of the two conductors which are effectively formed by the sets of segments 11 as previously explained.

The two-conductor line thus effectively formed and excited at one end by the source of electromagnetic energy is caused to radiate that energy in the desired pattern by unbalancing it at predetermined intervals. This is accomplished by imparting to selected ones of the series capacitors, which are formed by the wall of tube 10 as previously explained, a value of capacitance which differs from that of the corresponding capacitors in the opposite conductor. This may be accomplished simply by making selected ones of conductive segments 11 of distinctive lengths.

To prevent undesired backward lobes in the resulting antenna radiation pattern, the unbalancing should preferably be accomplished in quarter wavelength couplets; that is, for each capacitor which is unbalanced as previously explained, there should be provided another similar unbalanced capacitor at a distance along tube 10 equal to about one-fourth the wavelength of the electromagnetic energy being radiated. The degree of unbalance can be varied, e.g. tapered, along the length of the tube, thereby further controlling the radiating pattern of the antenna structure provided thereby.

The orientation of the radiation pattern produced by the structure of FIG. 1 varies with variations in the frequency of the electromagnetic energy radiated thereby. Therefore, if a fixed pattern is desired, the range of frequencies which can be radiated by the antenna is limited. The permissible range of such frequencies, i.e. the antenna bandwidth, can be substantially enlarged over that of the structure of FIG. 1 by combining series capacitive loading with shunt inductive loading of the conductors.

An arrangement having both forms of loading is shown in FIG. 3, to which reference may now be had.

In that figure the reference numeral 16 denotes each of a plurality of inductors formed of spiral conductive coatings on the surface of tube 10. From the inner end of each spiral 16 a connecting conductor, which may be formed of a metal eyelet, for example, leads to an interior conductor 17 which connects to element 11d. From the outer end of spiral 16 another conductor 18 connects to element 11a. These spirals 16 and their connecting conductors 17 and 18 constitute the shunt inductors.

A characteristic of antenna structures which is highly desirable in some applications is the ability to vary their radiation pattern without resorting to mechanical movement or deformation of the antenna structure.

Such characteristic can be imparted to antenna structures in accordance with this invention in the manner

illustrated in FIGURE 4, to which reference may now be had. In that figure a segment 20 of ribbon, rolled up into tube form similarly to tube 10 in FIG. 1, for example, is coated with longitudinally spaced segments 21 of conductive material. Rather than alternating between the outside and inside of the tube, as do segments 11 in FIG. 1, segments 21 in FIG. 4 are all on the outside of the tube. Between each two successive conductive segments 21, there is connected a capacitor 22, which responds to variations in the D-C potential applied thereto to vary its capacitance. Such capacitors are commercially available under the name "Varactor." In accordance with the present invention, these capacitors 22 are preferably attached directly to the surface of the tube, as by being glued thereto. They are connected to the adjacent segments 22 by suitable electrical conductors which may, for example, take the form of conductors such as used in printed circuits.

Radio frequency signals for radiation from the antenna structure of FIG. 4 may be applied thereto from a conventional source 25 of such signals via conventional R-F transformer 26 and coupling capacitors 27 and 28.

The variable D-C for control of the capacitors of element 22 may be supplied from a conventional D-C source 29, via potentiometer 30 and R-F chokes 31, 32. By adjusting potentiometer 30, the directivity of the antenna structure of FIG. 4 may be controlled.

As in the arrangement of FIG. 1, the electrical connections to the antenna structure which are shown in FIG. 4 are preferably made at one end of the array of elements 21 constituting the radiating portions of the antenna. It will be understood that, at the opposite end of this array, the elements 21 on opposite sides of the tube are electrically connected together, for D-C, at any rate, so as to establish a closed path for D-C from source 29.

The variable capacitors 22 of FIG. 4 are sufficiently flat so that they do not protrude far enough above the surface of ribbon tube 20 to interfere with rolling this ribbon up into a spool, in its flattened form. Should it be desired to reduce further the protrusion of these capacitors, they may be recessed in depressions in ribbon tube 20.

An antenna structure in accordance with this invention and particularly suited for operation with radio-frequency waves which are polarized transversely to the longitudinal axis of the antenna is illustrated in FIGURE 5, to which reference may now be had. The structure shown in FIG. 5 is similar to that of FIG. 1 in that it comprises a ribbon tube 40, and sets of conductive segments 41 disposed in two rows along diametrically opposite longitudinal areas of the tube. The conductive segments of each set are alternately placed on the inside and outside of the tube wall, and successive segments overlap partially in the longitudinal direction.

In addition, in the embodiment of FIG. 5, longitudinal segments 42 of conductive material, made and applied in the same manner as segments 41, are positioned on the outside surface of tube 40, one such segment 42 being preferably placed in each gap between outer wall segments 41.

Each pair of diametrically opposite segments 42 is connected together by a peripheral conductive strip 43 also applied to tube 40 in the same manner as segments 41.

To the free end of each additional segment 42 there is attached, via wires 44, 45, a vane 46 of conductive material. The wires 44, 45 are preformed so as to assume, when externally unrestrained, the quarter-circle configurations illustrated in FIG. 5. They are, however, sufficiently flexible so that they can be bent until they lie flat against the surface of tube 40. At the same time, they are sufficiently resilient so that they will reassume the form shown in FIG. 5 when whatever force causes them to lie parallel to tube 40 is removed. These wires may conveniently be

formed of piano wire appropriately heat and stress treated to produce the physical characteristics described above. Vanes 46 are preformed so as to take on a slightly curved shape, conforming to the external curvature of tube 40, when wires 44, 45, and vanes 46 with them, are caused to lie flat against that tube. Vanes 46 are made sufficiently thin to be flexible enough to be rolled up into a spool along with the ribbon of which tube 40 is formed. At the same time vanes 46 are made sufficiently thick that they stand out straight, away from tube 40, when that tube is formed through unrolling of the ribbon spool. A suitable material of which vanes 46 may be made is beryllium copper.

In the antenna structure of FIG. 5, coupling between the R-F conducting structure formed of elements 41 and the dipoles formed by vanes 46 is established by the additional longitudinal segments 42. To make this antenna structure primarily effective for transversely polarized R-F radiation, the radiation capability of elements 41 is preferably kept at a minimum. This may be achieved by keeping the diametrically opposed sets of elements 41 balanced, i.e., as nearly similar in physical configurations and characteristics as practical.

As previously pointed out, antenna structures in accordance with this invention are particularly suitable for use in outer space environments. One of the most severe stresses to which they are subjected in that environment is due to the fact that some portions may be exposed to the intense heat of the sun at the same time that other portions, not directly illuminated by sunlight, may be exposed to intense cold. Typically, one half of the periphery of the tube supporting the active antenna elements may be exposed to sunlight, while the other half is not. Such unequal solar heating of opposing halves of the periphery will tend to cause bending of the antenna structure in a longitudinal direction, due to the fact that the heated half expands while the unheated half does not. Since antenna structures in accordance with the invention will normally have appreciable lengths, e.g., fifty, or one hundred feet, or even more, and since the temperature differences between opposing halves may be very great, the bending caused thereby will, unless special care or precautions are taken, become so great as to distort appreciably the radiation pattern of the antenna.

I have found that the use of epoxy fiberglass for the ribbon tube of the antenna structure minimizes bending due to the above-mentioned causes, particularly when this fiberglass is present in the tube primarily with its fibers aligned generally with the long axis of the tube. For greater mechanical strength it may be desirable to add, at intervals, a reinforcing band of fiberglass with its fibers oriented generally transverse to the longitudinal axis of the tube. For a tube having a diameter of about one inch such reinforcing bands may be spaced between about one and two inches apart. Each band may be about one-quarter inch wide and may approximate the remainder of the tube wall in thickness.

For further protection against the distortion due to unequal solar heating effect described above, an antenna structure in accordance with this invention may be provided with a segmented external heat shield, as shown in FIGURE 6, to which reference may now be had. This heat shield is formed of segments 60 spaced from each other longitudinally along the ribbon tube 61. Each segment 60 may be made of a material having high terminal conductivity, such as aluminum, for example. Ribbon tube 61, on the other hand, is made of fiberglass, as in the other embodiments previously described. Both the inner tube 61 and the outer segments 60 are formed of ribbons of their respective materials which are stored flat in a spool and which assume their tubular configurations when unwound from the spool. In order to insure that the tubular segments 60 encircle the tube 61, rather than becoming interleaved in the overlapping portions of the latter, segments 60 are preferably made of substantially wider

ribbon than tube 61. This makes it possible, when unwinding, to keep segments 60 flattened out, by means of their protruding edge portions until after tube 61 has formed. When subsequently released, segments 60 will form encircling tube 61. To make sure that segments 60 are formed at their proper longitudinal positions with respect to tube 61, each segment 60 is preferably attached, at one end of the segment, to a non-overlapping portion of tube 61.

The way in which segments 60 contribute to the solution of the unequal solar heating problem is as follows. Due to their good thermal conductivities, they distribute the heating effect nearly equally about their circumference. As a result, they redistribute the heating effect to the shaded side of the fiberglass tube 61, in those areas covered by the segments 60. Moreover the segments 60, themselves, expand and contract longitudinally in response to heating and cooling, respectively, but they do so substantially equally at all peripheral positions. Because of this, and because at one end each of them is free to slide longitudinally with respect to tube 61, they do not tend to introduce any distortion into that tube.

Although not limited thereto, it will be understood that the arrangement of FIG. 6 is particularly suitable for an antenna structure such as shown in FIG. 5, the spaces between segments being suitable for placement of the dipole elements (46 in FIG. 5). The portions covered by segments 60 would be provided with conductive elements on the inside of the fiberglass ribbon tube. It will be recalled that, in FIG. 5, the radiation from these conductive elements is preferably minimized. The electrical shielding effect of segments 60 would therefore not be detrimental to such a structure.

By proportioning segments 60 so that each of them has a length equal to about one-half the wavelength of the radiated energy and is spaced by a similar amount from the next such segment, these segments can themselves be made into sets of quarter wave chokes imparting to the resultant structure a broadside radiation pattern with longitudinal polarization.

In the event that bending due to unequal heating effects nevertheless exceeds the permissible tolerances on deformation of the antenna structure, then the fiberglass ribbon tube may be used, not to support separate antenna elements along its entire length, but rather as a bow-like support structure. In such arrangement, illustrated diagrammatically in FIGURE 7, the fiberglass tube 65 may serve as a bowed support structure, the antenna itself, shown in FIG. 7 in the form of a two-wire transmission line 66, being attached to the end of tube 65 remote from its windup spool 67. The end of line 66 which is not attached to tube 65 is preferably resiliently fastened, as in a spring-loaded take-up reel 68, permitting the line 66 to accommodate itself to changes in curvature of tube 65.

It will be understood that many variations of the arrangements described above are possible without departing from the inventive concept. For example, many other means for introducing signals into the antenna structures will appear. Also the reversible characteristics of antennas for transmission and reception are well known and, accordingly, the adaptation of the structures disclosed to the reception of electromagnetic radiation will be apparent. In view of those and other possible variations I desire the scope of the invention to be limited only by the appended claims.

I claim:

1. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, with electrically conductive elements coated on said ribbon, said elements including segments longitudinally spaced apart from each other and arranged in two rows, so positioned as to be

substantially diametrically opposed to each other on the periphery of said tube.

2. The antenna structure of claim 1 further comprising electrically variable capacitors connected between the segments in each said row.

3. The antenna structure of claim 1 further comprising inductors connected between segments in said rows.

4. The antenna structure of claim 1 further characterized in that alternate ones of the segments in one said row are on the inside and on the outside of said tube, respectively.

5. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, with electrically conductive elements coated on said ribbon, and including separate segments disposed alternately on opposite sides of said ribbon.

6. The antenna structure of claim 5 further characterized in that said elements on opposite sides at least partially overlap one another.

7. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, comprising fiberglass and having tubular segments, which are wider circumferentially of the tube than the transverse width of the ribbon composing the tube, encircling said tube at longitudinally spaced positions therealong and contiguous therewith.

8. The antenna structure of claim 7 characterized in that said tubular segments are made of electrically conductive material, each have a length equal to about one half the wavelength of the electrical energy processed by the antenna, and are separated from each other by a distance also equal to about one half said wavelength.

9. The antenna structure of claim 7 further characterized in that said tubular segments are made of a material having high thermal conductivity.

10. The antenna structure of claim 9 further characterized in that one end of each said tubular segment is free to move longitudinally relative to said fiberglass tube.

11. The antenna structure of claim 10 further characterized in that the other end of each said tubular segment is restrained against movement longitudinally of said tube.

12. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, and further comprising a plurality of electrically conductive elements resiliently attached to spaced portions of said tube and capable of alternately being flattened against the wall of said tube and extending away from said tube substantially transversely to the longitudinal direction of said tube.

13. The antenna structure of claim 12 further characterized in that said conductive elements are electrically connected together in pairs, each said pair forming a dipole antenna element.

14. The antenna structure of claim 13 further comprising electrically conductive elements extending longitudinally of said tube, said dipole elements being electrically coupled to said longitudinal elements.

15. An antenna system comprising: an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material; electrical energy conductive means supported on and contiguous with a surface of the ribbon; and means for coupling electrical energy to and from said conductive means.

16. The antenna system of claim 15 characterized in that said conductive means comprises spaced apart electrically conductive segments extending longitudinally of said tube, and variable capacitance means coupling said segments to each other.

17. The antenna system of claim 16 characterized in that said variable capacitance means are capacitors responsive to variations in an applied potential to vary their capacitances.

18. The antenna system of claim 17 further comprising means for applying a variable potential to said capacitors.

19. The antenna system of claim 17 in which said electrical energy is high-frequency electromagnetic energy.

20. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, comprising fiberglass with its fibers aligned principally generally parallel to the longitudinal axis of said tube, and having spaced portions provided with additional fiberglass material having its fibers oriented principally transversely to said longitudinal axis.

21. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, and further comprising an antenna including an elongated electrical energy radiating structure attached at one of its ends only to said tube in the vicinity of one end of said tube and extending externally of said tube flexibly outward from its attachment to said tube and substantially perpendicular to the longitudinal axis of the tube.

22. An antenna structure comprising an elongated ribbon capable of being rolled up flat into a spool and forming when unrolled from said spool a tube having overlapping longitudinal edge portions, said ribbon being made of electrical insulating material, and further comprising an antenna with electrically conductive elements on said ribbon, said elements including segments longitudinally spaced apart from each other and at least a plurality of said segments being on the inside when the ribbon is in tubular form.

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