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SLOTTED CYLINDRICAL ANTENNA SYSTEMS

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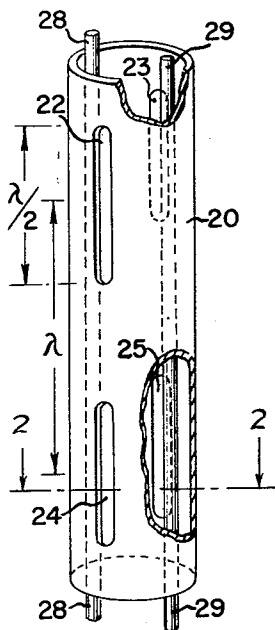


Fig. 1.

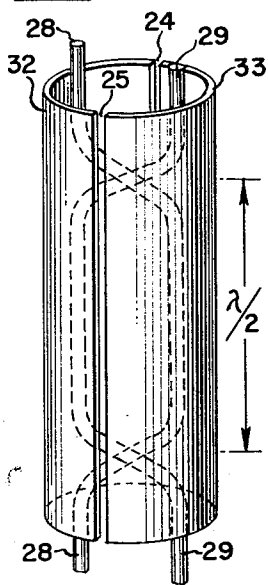


Fig. 4.

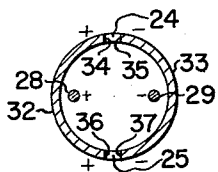


Fig. 2.

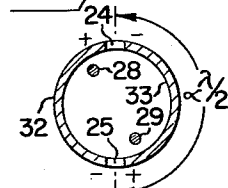


Fig. 3.



Fig. 5.

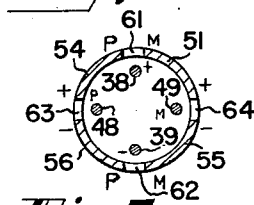


Fig. 7.

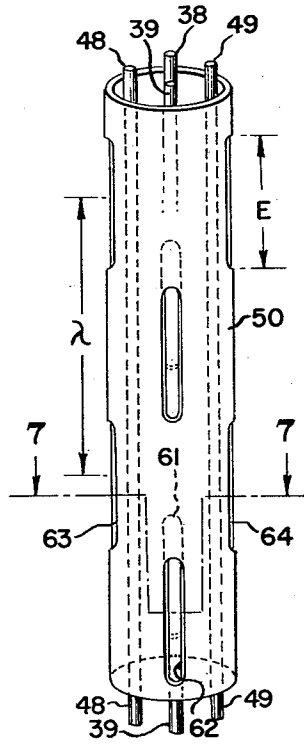


Fig. 6.

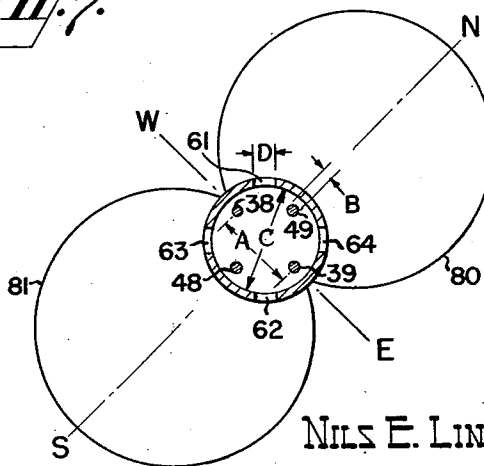


Fig. 8.

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2,803,008

SLOTTED CYLINDRICAL ANTENNA SYSTEMS

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19 Claims. (Cl. 343-770)

The invention relates to slot antennas and particularly pertains to an ultrahigh frequency slotted cylinder antenna array.

Broadcasting of television program service in the ultrahigh frequency band between 470 and 1000 megacycles/second imposes severe requirements for the necessary antenna systems. Effective radiated powers of 100 to 200 kilowatts are necessary, and a power handling ability up to 1000 kilowatts of effective radiated power is desirable. Antenna power gains to obtain up to 200 kilowatts of effective radiated power must be of the order of 20 to 30 times that of a simple tuned dipole to permit these high values of effective radiated power to be obtained with transmitter equipment of good efficiency and nominal power output. The dimensions of such a radiation system in the ultrahigh frequency bands are much smaller than for the lower frequencies so that there is less than sufficient room for the prior art type of transmission line assemblies.

It is an object of the invention to provide an improved ultrahigh frequency, omnidirectional, high power antenna system of simple construction for operation over a relatively wide frequency band.

It is another object to provide a slot antenna system having a simple, centrally-located balanced transmission line.

These and other objects of the invention which will appear as the specification progresses are attained by means of a transmitting or receiving antenna system comprising a hollow tubular conductive member having a plurality of elongated longitudinal slots arranged along the length of the member in pairs or groups of slots spaced about the periphery. Radio frequency energy is distributed to the plurality of slots from an externally located transmitting transducer or collected from the slots and delivered to a receiving transducer by a balanced transmission line comprising a pair of conductors spaced apart on opposite sides of the longitudinal axis of and located within the tubular conductive member. The conductors are spaced from the interior wall portions of the tubular conductive member so as to induce current flow therein and are located at such angles with respect to the slots as to properly polarize the edges of the slots for radiation or reception of energy to and from ambient space.

In one basic embodiment of the invention a pair of longitudinal slots are located diametrically opposite each other in the wall portions of a conductive cylinder and the conductors of a balanced transmission line are located in a plane passing through the axis of the cylinder and normal to the plane passing through both slots. The opposing edges of the slots will be at the same instantaneous polarity while the opposing edges of each slot will be of opposite polarity to effect a transfer of energy between the conductors of the transmission line and ambient space.

Another basic embodiment of the invention comprises a cylinder having four such slots located at intervals of ninety degrees about the periphery of the cylinder. One pair of transmission line conductors are located in the

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plane passing through one pair of diametrically opposed slots to energize the other pair of slots as herein before described. Another pair of transmission line conductors are similarly located in the plane of the other slots to energize the first slots without interaction between the other slots due to the same polarization of apposing edges of the one pair of slots. The conductors of the transmission lines are arranged with the median planes intersecting at the axis of the cylinder thereby to prevent interaction between the balanced transmission line currents directly. The arrangements above described may be stacked one on top of the other provided the centers of the slots are spaced in the vertical direction substantially a wavelength, or a multiple thereof, apart to insure proper phase relationship of the slots on any given side of the cylinder. Where a dual-transmission line feed is used it is preferable to place the slots energized by one transmission line in a different level from that in which the slots excited by the other transmission line are located.

An alternate construction of the basic embodiment comprises a pair of semi-circular members arranged to form a tubular structure having a pair of continuously extending slots. The transmission line is transposed every half wavelength in order to properly polarize the edges of the slots. This assembly is also adaptable for four slots and two transmission lines fed by staggering the transpositions of the two transmission lines.

Either standing wave or travelling wave energy may be applied to the transmission lines. If travelling waves are used, the transmission lines are terminated by impedance elements matching the transmission line characteristics or the energy may be returned over a shielded transmission line preferably located at the axis of the cylinder. Standing wave energy, however, is considered the more practical form for applications.

In order that the invention may be more clearly understood and readily put to practical use, circuit arrangements embodying the invention are hereinafter described, by way of example only, with reference to the accompanying drawing in which:

Fig. 1 is an elevation view of an antenna system according to the invention;

Fig. 2 is a cross-section view taken along the line 2-2, of a portion of the antenna shown in Fig. 1 illustrating essential details of an antenna system according to the invention;

Fig. 3 is a cross-section view of another alternate arrangement of the antenna of the invention;

Fig. 4 is an elevation view of an alternate embodiment of an antenna according to the invention;

Fig. 5 is a cross-section view of still another alternate arrangement of the antenna of the invention;

Fig. 6 is an elevation view of another embodiment of the antenna according to the invention;

Fig. 7 is a cross-section view of the antenna according to the invention as shown in Fig. 6 taken along the line 7-7.

Fig. 8 is an illustration of an alternative arrangement together with a graphical representation of the field pattern obtained therewith.

Referring to Fig. 1, there is shown an elevation view of an antenna system according to the invention. The radiation transferring element consists of a cylinder 20, which in practice is usually a galvanized steel tube, having oppositely disposed longitudinally arranged elongated apertures or slots 22-25 therein. The term "cylinder" as used herein is considered to be the surface traced by any straight line, called generatrix or element, moving parallel to a fixed straight line, according to Webster's New International unabridged dictionary, 1953 edition. These slots as shown are approximately a half wavelength long at the operating frequency and are spaced a wave-

length apart between their centers. Variations of these dimensions will be apparent to those skilled in the art. For example, the thickness of the tube will provide some capacitive reactive loading, calling for a corresponding shortening of the slots to compensate. In practice the slots are usually either filled in or covered with an insulating material which also affects the dimensioning.

The slots 22—25 are preferably covered by polyethylene slot covers held in place by end and side clamping fixtures. A convex construction of slot covers is preferably employed to reduce the area of the slots in which high frequency currents flow. The use of the protruding slot covers also prevents deleterious effects of certain wind velocities on the tube 20 which may set up a harmonic vortex wave.

A pair of elongated conductors 28 and 29, preferably tubular for practical reasons, are arranged within the cylinder 20. These conductors are of such diameter and are spaced apart at a distance at which a balanced transmission line is effected at the desired operating frequency. Further, according to the invention, the relationship of the diameter of the transmission line conductors 28, 29 to the inner diameter of the cylinder 20 is such that energy present in the transmission line is effective to induce a current flow at the operating frequency in the wall portions of the cylinder 20 and thus excite the slots 22—25.

A cross-section view of the antenna system is shown in Fig. 2, wherein the balanced transmission conductors 28, 29 are located in a plane substantially at right angles to any plane passing through both of the slots 24, 25.

The conductive surface element formed by the wall portion 32 of the cylinder 20 lying between the slots 24, 25 and nearest one of the conductors 28 will have currents of given intensity and direction of flow or polarity opposite to the direction of flow or polarity of currents of the same intensity in the other wall portion 33 induced by the proximity of the other conductor 29. Thus the apposite edges of the slots 24 and 25 are of opposite instantaneous polarity as required for radiation.

In the interest of clarity and convenience the longitudinal edges of each pair of slots which lie diametrically opposite each other or which appear in the same relative position in a traverse about the periphery in a single direction are hereinafter termed the corresponding edges, and the edges which are immediately opposite each other are termed the opposing edges as against the apposing of the same slot. For example, edges 34 and 35 of the section shown in Fig. 2 are apposing edges, as are edges 36 and 37. Edges 35 and 36 which are diametrically opposite each other are corresponding edges, while opposing edges 35 and 37 are immediately opposite each other. With respect to a given edge 34, the edge 35 of the same slot is the apposite edge; the immediately opposing edge 36 is the opposite edge, and the diametrically opposite edge 37 is the corresponding edge.

At the same time the opposing edges of the slots 24, 25 are at the same instantaneous polarity, providing the advantages set forth in U. S. Patent 2,660,670 issued November 24, 1953 to Dr. George H. Brown. These current conditions are afforded without any restrictions on the circumferential dimensions of the cylinder 20.

Offsetting of the slots 24, 25 with respect to the conductors 28, 29 can be effected if the circumferential dimensions are chosen accordingly. An example of such an arrangement is shown in Fig. 3, wherein the circumference of the cylinder 20 is approximately one wavelength, at the operating frequency. Each wall portion 32, 33 between two radiating slots 24, 25 should be an electrical half wavelength, or an odd multiple thereof, at the operating frequency so that each end of each portion will be of opposite instantaneous polarity with respect to the other end due to the time for the current wave to travel the distance. In this arrangement corresponding edges will be of the same polarity as distinguished from the polarity relationship of the arrangement of Fig. 2.

A variation of the antenna system according to the invention is shown in Fig. 4 wherein two conductive surface elements 32 and 33 of semi-circular cross-section are arranged to form a substantially tubular structure having two continuous slots 24 and 25 therebetween. In this instance the transmission line conductors 28, 29 are transposed every half wavelength at the operating frequency in order to maintain the edges of the slots in the proper polarity. A cross-section taken transversely through the structure of Fig. 4 will be the same as that shown in Fig. 2, and the same explanation of the mode of operation will hold except for the transposition point at which little or no radiation will take place anyhow.

The effect of additional slots on the antenna system of the invention as thus far described can be seen by referring to Fig. 5. The cylinder contains four slots 24, 25, 42 and 43 spaced ninety degrees apart. Transmission line conductors 38 and 39 induce currents in the contiguous wall portions 44 and 45 which follow the rules hereinbefore set forth. The interposed wall portions 46 and 47, however, are neutral in effect and the whole radiation transferring element acts as though the slots 24, 25, 42 and 43 are in series respectively.

A more versatile embodiment of the invention is shown in Figs. 6 and 7. A length of radiation transferring element 50 has two groups of four slots each, for example the slots 61—64, spaced about the periphery and two balanced transmission lines comprising the conductors 38, 39 and 48, 49 respectively arranged within the tubular element 50 for energizing the slots. The corresponding slots of each group are spaced apart by a wavelength, or a multiple thereof, at the operating frequency. The slots of each group may be on the same level, but preferably alternate slots of each group are staggered by half a wavelength as shown in Fig. 6. The cross-section taken along the line 7—7 of Fig. 6 shows the slots in Fig. 7 in the same manner as though they were on the same level for clarity of explanation and also to show that such a structure is feasible, although not the preferred embodiment.

One conductor 38 of one transmission line induces currents of equal intensity in the contiguous wall portions 54 and 51 which places the apposing edges of the adjacent slot 61 at the same instantaneous potential and the other conductor 39 induces currents of opposite polarity in both of the contiguous wall portions 55 and 56 which place the apposing edges of the adjacent slot 62 at the same instantaneous potential. Thus the slots 61 and 62 adjacent the conductors 38 and 39 respectively of the one transmission line do not radiate any energy travelling down this transmission line. For this reason staggering of the slots is to be preferred in order to provide solid wall portions—which is above the slots 61 and 62 in the view of Fig. 6—contiguous to the conductors for more efficient transfer of energy. Of course another reason for staggering the slots is to minimize the effect of any disturbing influence outside the cylinder 50 on the conductors within the area of maximum energy transfer to the wall portions. The energy travelling down the transmission line comprising the conductors 38 and 39 is radiated by the other pair of slots 63, 64 because apposite edges of the slots 63 and 64 are of instantaneous opposing polarity. That is, the opposing edges of the radiating slots 63 and 64 nearest the one transmission line conductor 38 will be of the same instantaneous polarity in response to currents induced by the conductor 38 in the contiguous wall portions 54 and 57, while the apposing edges of each of the radiating slots will be of the opposite instantaneous polarity in response to energization by the other transmission line conductor of the other wall portions 55 and 56. Likewise, the conductors 48 and 49 of the other transmission line energize the slots 61 and 62 located in a plane and right angles to the plane defined by the conductors 48, 49 and have no effect on the slots 63, 64 lying in the same plane. Thus there is no interaction between pairs of slots.

The two pairs of transmission line conductors 38, 39 and 48, 49 are preferably equidistantly located from the center of the tubular member 50 in order to prevent any interaction therebetween. It is not an absolute necessity, however, that the conductors all be spaced the same distance from the center. It will be sufficient if the median planes of the transmission line conductors interact at the center. The median plane is defined as the plane normal to the plane defined by the conductors and passing through a point midway between them. Hence the transmission line conductors may be considered to lie at the corners of a rhombus, preferably a right rhombus or square, whereby interaction is avoided. Energy of phase quadrature relationship in the two transmission lines will effect turnstile radiation providing an omnidirectional field pattern of contra-rotating phase vectors such as is used in the better television broadcasting installations today. Other applications of the structure will be immediately suggested to those skilled in the art.

Another embodiment of the invention is shown in cross-section in Fig. 8, wherein the conductors 38, 39 and 48, 49 are positioned to be near the centers of the wall portions separating the slots 61-64. The two transmission lines each energize the four slots as explained in connection with the structure shown in Fig. 5. This embodiment was built and successfully operated at frequencies in the band 800-900 megacycles with the following dimensions, all in inches:

Conductor spacing A.....	3%
Conductor diameter B.....	%
Cylinder diameter C.....	4.5
Slot width D.....	0.43
Slot length E.....	7.0

Curves 80 and 81 representative of the field pattern obtained by excitation by means of the transmission line conductors 48 and 49 alone are superimposed on the cross section. These curves are nearly perfect circles. Similar curves were obtained by energizing the slots by means of the transmission line conductors 38, 39 in phase quadrature and the resultant pattern was substantially perfectly circular. In this determination the antenna was excited as a transmitting antenna but it must be understood that inverse operation as a receiving antenna will be equally efficient. The arrangements described in connection with the description of Figs. 5-8 can be modified along the lines suggested in connection with the arrangement shown in Fig. 4. With two balanced transmission lines it is necessary that the transposition of one line be made substantially midway between the transposition of the other line; which is in effect equivalent to staggering of the slots as shown in Fig. 6. The four continuously extending slots will effect a vertical array of better directivity than that afforded by antenna of equal height according to the arrangement of Fig. 6 but due to some losses at the transposition points the efficiency probably is not as great as could be obtained with an antenna according to Fig. 6 of twice the height. Cost and other factors will determine the ultimate construction for each case at hand.

It is also suggested that in accordance with the invention the elongated slots may also be skewed with respect to the axis of the hollow tubular conductive member, in which case elliptical or circularly polarized waves result. The antenna of the invention may be prevented from icing and the like by blowing hot air up the tubular members 20 or 50 by a heater-blower combination (not shown) located at the base. For high power and high temperature operation of the slotted cylinder antenna, cooling air may be blown into the tubular member.

Since the length of the conductive cylinder 20 or 50 may be from 20 to more than 40 feet for ultrahigh frequency television broadcasting service depending upon the gain required, it is desirable to employ several sets of centering spacers. Three or four such spacers may be

used at each of several layers along the length of the outer conductive cylinder to maintain the energy distribution between the transmission line formed by conductors 38, 39 and 48, 49 in perfectly neutral relationship. Each spacer is made of insulating material. It has been found that a polytetrafluorethylene material marketed under the trade name "Teflon" has highly desirable mechanical properties which combine a high insulation resistance, low dielectric loss, and low friction coefficient. Holes are provided in each spacer to allow moisture condensation to drain and also for passage of heating and cooling air, if desired.

The invention claimed is:

1. An antenna system including a tubular conductive member having elongated apertures disposed in opposing wall portions thereof and a two-conductor open-type transmission line arranged within said tubular conductive member, said tubular conductive member and said conductors being located with respect to each other so as to couple energy between said transmission line and said apertures by inducing currents in said wall portions of said tubular conductive member.

2. An antenna system including at least two elongated conductive members arranged and spaced apart to form a tubular structure having a pair of oppositely disposed elongated apertures between said members, two elongated conductors arranged within said tubular structure and spaced apart from each other and from said conductive members at distances at which high frequency energy translated by currents in said conductors is coupled through said conductive members and radiated in ambient space by way of said elongated apertures.

3. An antenna system including an elongated hollow conductive member having at least two pairs of slots therein, the slots of each pair being longitudinally arranged in said member on substantially opposite sides thereof, a pair of elongated conductors arranged within said conductive member effecting an open-wire transmission line, a further pair of conductors arranged within said hollow conductor to form another open-wire transmission line, the median planes defined by the first said and said further pairs of conductors intersecting at the axis of said hollow conductive member, and means to couple transducer apparatus across said open-wire transmission lines.

4. An antenna system including an elongated hollow conductive member having at least two slots therein, said slots being longitudinally arranged in said member and in opposing portions thereof, a pair of conductors arranged within said conductive member and spaced apart to effect an open-wire transmission line, said slots being coupled to said transmission line by currents induced in said conductive member, and means to couple transducer apparatus across said transmission line.

5. A slot antenna comprising a hollow tubular conductive member having a plurality of elongated slots therein, each of said slots having a length of substantially a half wavelength at the operating frequency, said plurality of slots being arranged in layers having a center-to-center spacing of a multiple including unity of one wavelength at said frequency from the next adjacent layer, elongated conductors disposed within said conductive tubular member and capacitively coupled to said tubular member at the walls thereof, each slot being coupled to a pair of said elongated conductors solely by means of currents induced in the walls of said tubular conductive member.

6. An antenna system including a radiation transferring element comprising a tubular conductive member having a plurality of longitudinally arranged elongated slots therein, a pair of conductors running longitudinally within said tubular conductive member and spaced apart to form a balanced transmission line, said conductors being further spaced from the inner walls of said tubular conductive member to render the sole coupling between said slots and said transmission line by transfer of energy

between said transmission line and said tubular conductive member.

7. An antenna system comprising a plurality of conductive surface elements arranged to form a substantially tubular structure having at least two elongated apertures between said elements, at least two conductors arranged within said tubular structure and spaced apart to effect a balanced transmission line, said conductors being free of connection to said conductive surface elements and spaced therefrom at a distance at which currents are induced therein to transfer high frequency radiation to and from ambient space.

8. An antenna system including a tubular conductive member having a plurality of elongated apertures arranged in wall portions thereof, said apertures being arranged in pairs with the slots of each pair located in opposing wall portions of said conductive member, a pair of elongated conductors arranged within said conductive member, each of said conductors being located adjacent a wall portion of said conductive member to induce currents therein in response to potentials applied between said elongated conductors, the currents induced by each of said elongated conductors producing potential differences transversely of said slots, thereby causing a transfer of energy between said elongated conductors and ambient space.

9. An antenna system including at least one balanced conductor transmission line, a plurality of conductive surface elemental portions arranged about and spaced from the conductors of said transmission line to enclose the same except for a number of apertures between said elemental surface portions, the spacing between said conductors and the dimensions thereof having values at which wave energy of the desired operating frequency is translated thereby, and the dimensions of said conductors and the spacing of the conductive surface portions therefrom being of values at which currents are induced in said portions and said wave energy is translated through said apertures between said transmission line and ambient space.

10. An antenna system as defined in claim 9 and wherein the distance that currents induced in said conductive surface elements travel in opposite directions is an odd multiple including unity of a half wavelength at the operating frequency.

11. An antenna system as defined in claim 9 and wherein the ratio between the diameter of a conductor and the spacing between that conductor and the contiguous conductive surface element lies between 0.15 and 0.20.

12. An antenna system as defined in claim 9 and where-

in the ratio of the diameter of a conductor squared to the product of the spacing between that conductor and the conductive surface element and the radius of curvature of that conductive surface element lies between 0.10 and 0.25.

13. An antenna system as defined in claim 9 and wherein said conductive surface elemental portions define continuous apertures and the conductors of said transmission line are transposed every half-wavelength at the operating frequency to energize each edge of said apertures in the same instantaneous polarity throughout the entire length thereof.

14. An antenna system as defined in claim 9 and wherein there are at least four conductive surface elemental portions and there are two apertures on either side of the plane defined by the conductors of said transmission line.

15. An antenna system as defined in claim 9 and wherein the capacitive reactance between the transmission line conductors is substantially resonated by the inductive reactance of the conductive surface portions carrying the induced currents to the edges of the apertures formed between said portions.

16. An antenna system as defined in claim 9 and wherein there are at least four conductive surface elements and each conductor of said transmission line induces substantially equal currents into two of said portions at the same instantaneous polarity.

17. An antenna system as defined in claim 16 and wherein the aperture remote from the transmission line conductors act as inductance elements in series with the capacitive reactance between the transmission line conductors and said conductive surface portions substantially to resonate said system at the desired operating frequency.

18. An antenna system as defined in claim 9 and wherein each of said apertures is of substantially a half wavelength and alternate apertures are in different levels.

19. An antenna system as defined in claim 16 and including a further balanced transmission line having the conductors thereof located in the median plane of the first said transmission line and equidistant from the conductors thereof.

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