

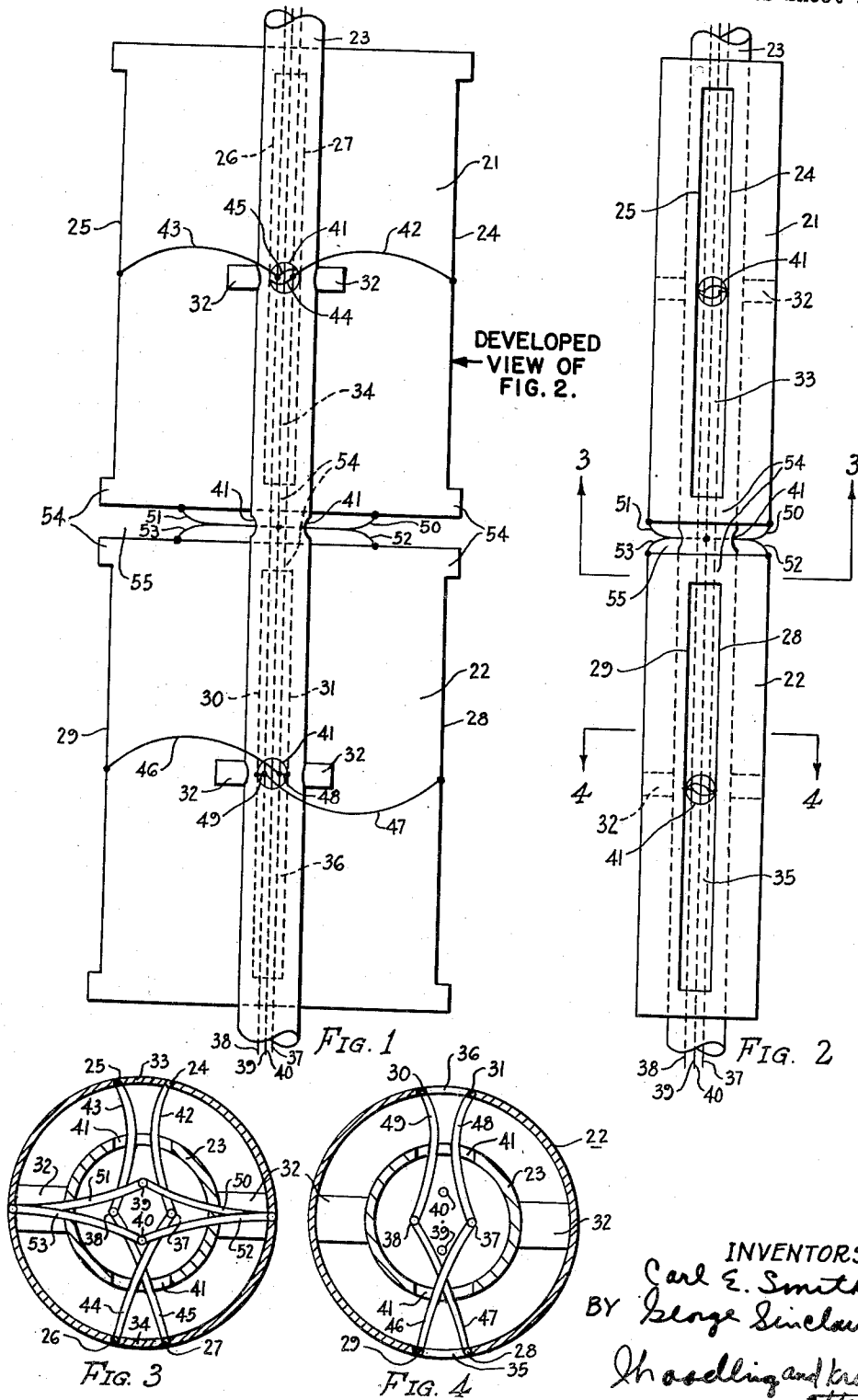
Jan. 5, 1954

C. E. SMITH ET AL
SLOTTED CYLINDRICAL ANTENNA

2,665,381

Filed Oct. 16, 1947

4 Sheets-Sheet 1



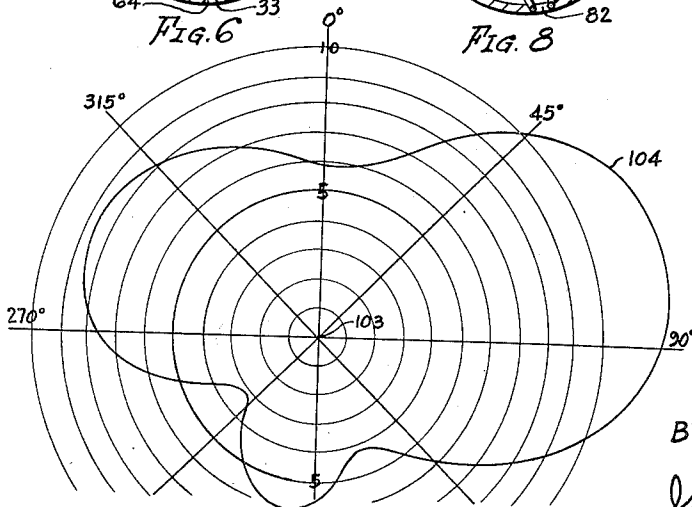
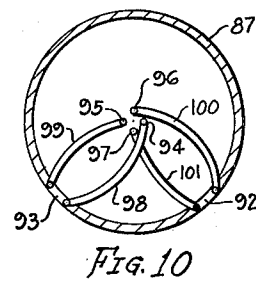
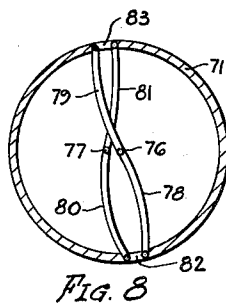
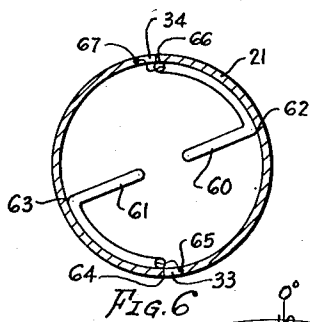
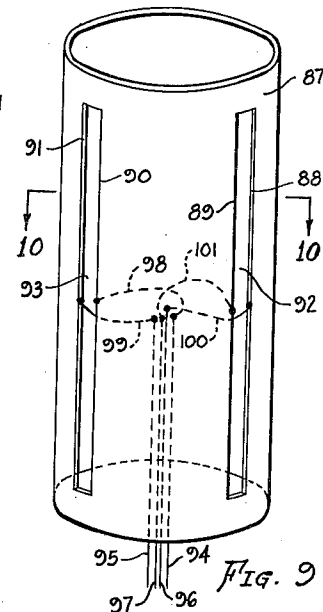
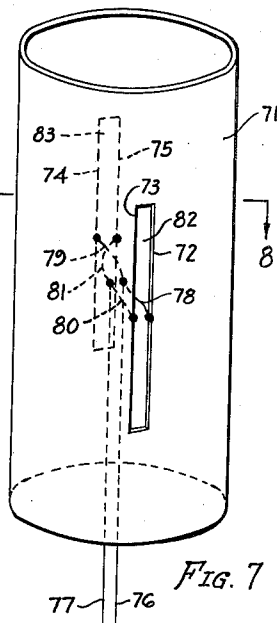
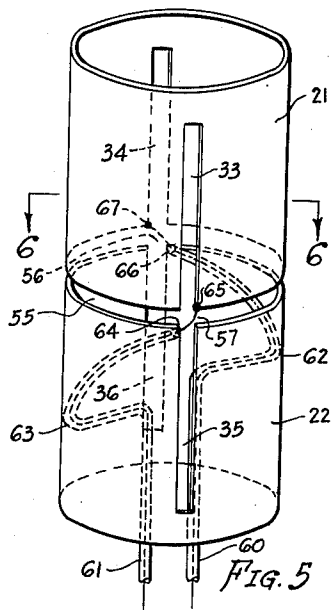
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4 Sheets-Sheet 2



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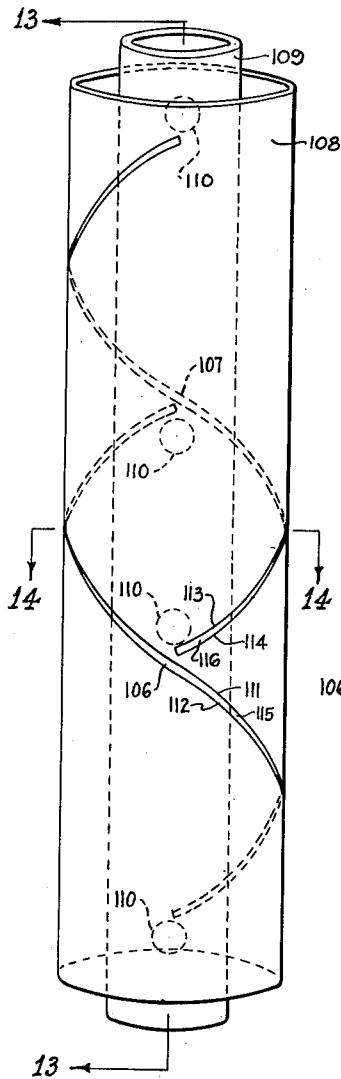


FIG. 12

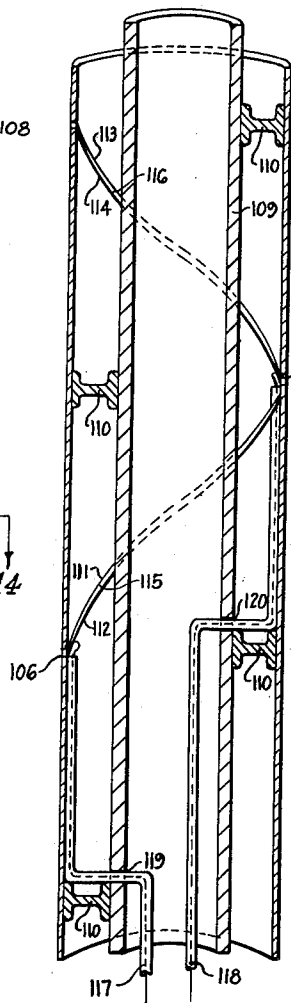


FIG. 13

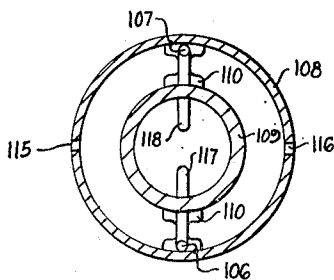


FIG. 14

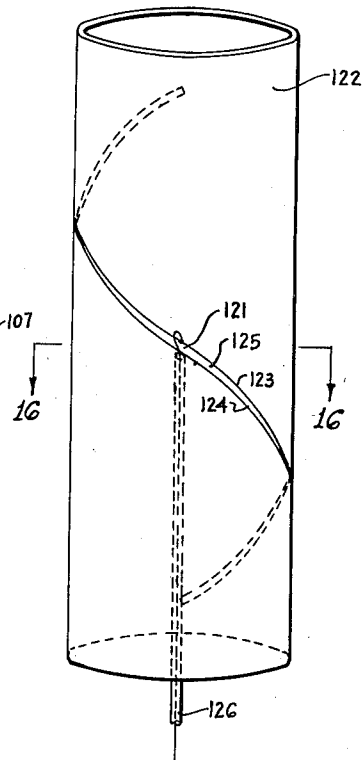


FIG. 15

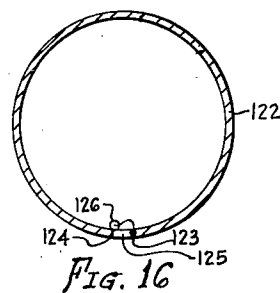


FIG. 16

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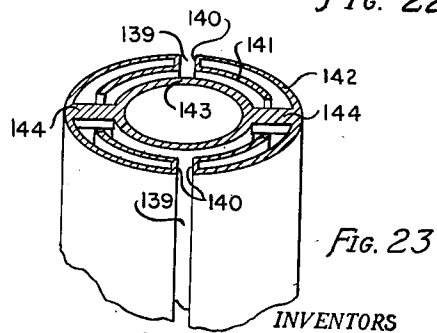
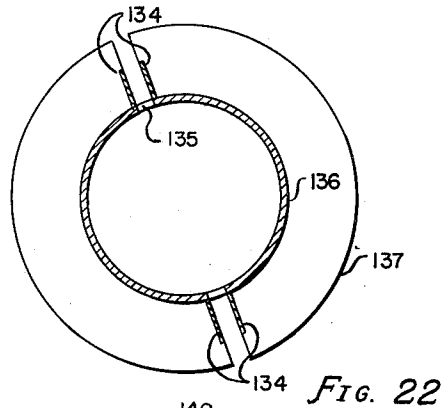
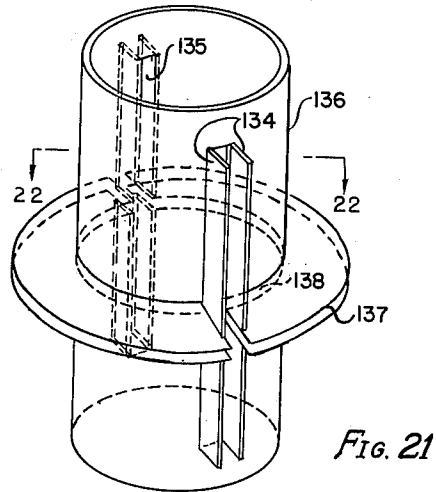
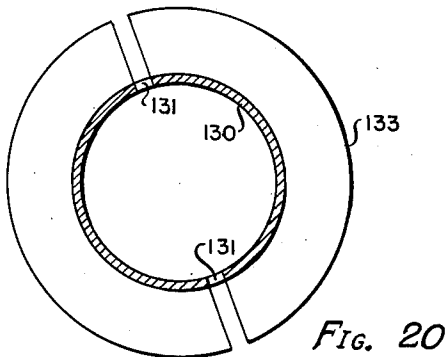
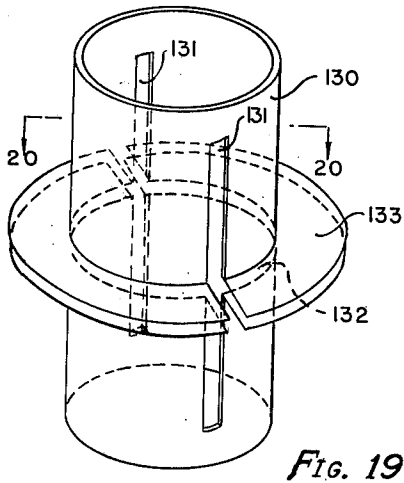
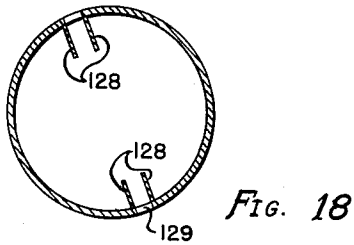
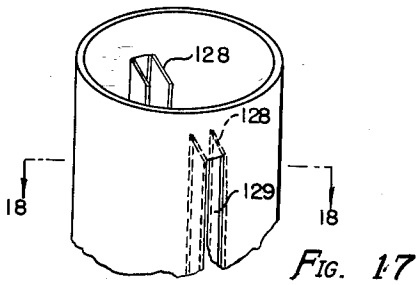
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4 Sheets-Sheet 4



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2,665,381

SLOTTED CYLINDRICAL ANTENNA

Carl E. Smith, Cleveland, Ohio, and George Sinclair, Toronto, Ontario, Canada, assignors, by mesne assignments, of one-half to said Smith and one-half to United Broadcasting Company, a corporation of Ohio

Application October 16, 1947, Serial No. 780,264

7 Claims. (Cl. 250—33)

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The invention relates in general to antennas for use with electromagnetic wave energy, and more particularly to conduits or hollow cylinders having slots therein for the radiation of the radiant energy waves.

An object of the invention is to provide an antenna having a high gain in the horizontal plane, with low wind resistance and with greater flexibility of control of the horizontal field intensity pattern for a given number of feed lines than is possible with normal dipoles.

Another object of the invention is to provide an antenna having a uniform gain in the horizontal plane and which is capable of being vertically stacked to increase the gain in the horizontal plane.

Another object of the invention is to provide an antenna to radiate circularly polarized electromagnetic waves with the horizontal field intensity pattern highly controllable as to nulls and/or circularity.

A further object of the invention is to provide a hollow cylindrical antenna having a spiral slot for effecting radiation of electromagnetic waves having both horizontal and vertical components.

A further object of the invention is to provide a hollow cylindrical antenna having two symmetrically placed vertical slots and a horizontal slot, with the vertical slots fed 90° out of phase relative to the horizontal slot, to effect circular polarization of the radiated electromagnetic wave with a high uniform gain in the horizontal plane.

A still further object of the invention is to provide a hollow cylindrical antenna having two non-symmetrically placed slots such that the horizontal field intensity pattern of the horizontally polarized wave is not symmetrical about any line in the horizontal plane.

Another object of the invention is to provide lips on the slots of a slotted cylindrical antenna to increase the capacity across those slots.

Another object of the invention is to provide capacity lips on the slots of slotted cylindrical antennas to affect the radiation pattern of the radiated wave.

A still further object of the invention is to provide internal fins attached to the edges of the slots of a slotted cylindrical antenna to increase the dimensions of the cavity behind the slot.

Other objects and a fuller understanding of the invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawing, in which:

Figure 1 is a developed view of the preferred embodiment of the invention;

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Figure 2 is a front elevational view of the preferred embodiment of the invention;

Figures 3 and 4 are cross-sectional views taken along the lines 3—3 and 4—4 of Figure 2;

Figure 5 is a perspective view of an antenna similar to the preferred embodiment, but with a different method of feeding;

Figure 6 is a cross-sectional view taken along the line 6—6 of Figure 5;

Figure 7 is a perspective view of a hollow cylindrical antenna having two symmetrical vertical slots for radiating horizontally polarized electromagnetic waves;

Figure 8 is a cross-sectional view taken along the line 8—8 of Figure 7;

Figure 9 is a perspective view of another antenna having two non-symmetrically placed vertical slots;

Figure 10 is a cross-sectional view taken along the line 10—10 of Figure 9;

Figure 11 is a graph showing the field intensity pattern in the horizontal plane obtainable from the antenna of the figures 9 and 10;

Figure 12 is a perspective view of a hollow cylindrical antenna having a right and left hand spiral slot;

Figure 13 is a cross-sectional elevational view taken along the line 13—13 of Figure 12;

Figure 14 is a cross-sectional view taken along the line 14—14 of Figure 12;

Figure 15 is a perspective view of a hollow cylindrical antenna having one spiral slot;

Figure 16 is a cross-sectional view taken along the line 16—16 of Figure 15;

Figure 17 is a fragmentary perspective view of a cylindrical antenna having inwardly turned lips on the vertical slots;

Figure 18 is a cross-sectional view taken along the line 18—18 of Figure 17;

Figure 19 is a perspective view of an antenna having capacity disks fastened to the edges of the horizontal gap of the antenna;

Figure 20 is a cross-sectional view taken along the line 20—20 of Figure 19;

Figure 21 is a perspective view of an antenna similar to that shown in Figure 5, but including outwardly turned lips on the vertical slots and capacity disks on the horizontal gap;

Figure 22 is a cross-sectional view taken along the line 22—22 of Figure 21, and

Figure 23 is a fragmentary sectional perspective view of a slotted cylindrical antenna having internal fins on the edges of the vertical slots to increase the cavity depth behind the slot.

The invention deals with antennas that have a slot or slots in a conduit, which conduit has been shown in the drawings and is preferably in the form of a hollow cylinder for the sake of symmetry. For further modifications of the invention, reference may be had to the co-pending application filed concurrently herewith, entitled "Three Slot Cylindrical Antenna," Serial No. 780,265. The preferred embodiment of the invention is shown in the Figures 1 to 4, and shows a hollow cylindrical antenna having an upper section 21 and a lower section 22 adapted to be supported by a mast 23. The Figure 1 is a developed view showing the hollow cylindrical upper and lower sections 21 and 22 slit open and laid into a flat sheet in order to more clearly show the connections. The upper section 21 has first and second edges 24 and 25 for defining a first slot 33, and third and fourth edges 26 and 27 for defining a second slot 34. The first and second slots 33 and 34 are symmetrically placed about the periphery of the cylindrical upper section 21, and are axially aligned with the mast 23. In a similar manner the lower section 22 has fifth and sixth edges 28 and 29 defining a third slot 35, and seventh and eighth edges 30 and 31 for defining a fourth slot 36. The third and fourth slots 35 and 36 are vertical and axially aligned with the mast 23, and are symmetrically spaced on the periphery of the lower section 22. The third and fourth slots 35 and 36 are spaced adjacent the first and second slots 33 and 34 on the upper section 21. The first, second, third and fourth slots, 33, 34, 35 and 36, serve as the means to radiate the electromagnetic waves, and in this preferred embodiment of this invention are made a half-wave length long relative to the wave length of the electromagnetic wave. The upper and lower sections 21 and 22 are separated to form a horizontal gap 55 therebetween and are fastened to the mast 23 at a point where the potential to the grounded mast is a minimum. Such points are found at the geometrical center of the periphery of the upper and lower sections between adjacent slots. Arms 32 are used to fixedly fasten the upper and lower sections 21 and 22 to the mast 23 at such points of minimum potential difference. Shorting bars 54 are used to close the ends of the vertical slots 33, 34, 35 and 36 adjacent the horizontal gap 55. These are not essential, but are at a voltage minimum point, since they are a quarter wave length distant from the feed point of the slots.

First, second, third and fourth axially aligned parallel conductors 37, 38, 39 and 40 are provided within the mast 23 to connect the antenna to some electrical device, such as a transmitter so that the antenna may radiate wave energy, or it may be a receiver such that the antenna may be receptive to such wave energy. The first and second conductors 37 and 38 are adapted to feed the first, second, third and fourth vertical slots, 33, 34, 35 and 36, and the third and fourth conductors 39 and 40 are adapted to feed the horizontal gap 55. By energizing the vertical slots, horizontal polarization of the radiated wave is effected, and by energizing the upper section against the lower section 22 vertical polarization of the radiated wave is effected. By establishing these two planes of radiation in 90° time phase displacement, elliptical polarization of the radiated wave is effected. By so making the amplitude of the horizontal and vertical components equal, the elliptically polarized wave becomes circularly polarized. The upper and lower sections

21 and 22 that effect vertically polarized radiation establish a substantially circular field intensity pattern in the horizontal plane since it is akin to a fat dipole. The vertical slots in the upper and lower sections 21 and 22 radiate horizontally polarized electromagnetic waves with the field intensity pattern in the horizontal plane substantially circular. The result of the combination of the circular horizontal field intensity patterns of both the vertically and horizontally polarized waves gives a substantially uniform gain in the horizontal plane with a substantially circularly polarized electromagnetic wave.

The first and second conductors, 37 and 38, are connected to the vertical slots by short feeder lines. The first conductor 37 is connected to the slot edge 24 by a feeder 42, and is connected to the diametrically opposite slot edge 26 by a feeder 44. The second conductor 38 is connected to the slot edge 25 by a feeder 43 and is also connected to the diametrically opposite slot edge 27 by the feeder 45. These feed connections are at the center of the first and second slots 33 and 34 in the upper section 21. The same first and second conductors 37 and 38 feed the third and fourth slots 35 and 36 in the lower section 22, the feed point for these slots being at the center thereof, which is substantially one-half wave length below the feed point for the first and second slots, 33 and 34. Since the feed point for the vertical slots in the lower section 22 is one-half the wave length distant from the feed point of the vertical slots in the upper section 21, the feeding connections are reversed in order to make the polarity of the waves emanating from the first and third slots 33 and 35 reinforce rather than oppose each other. The same is true of the waves emanating from the second and fourth slots 34 and 36. To feed the third and fourth slots, the first conductor 37 is connected to the slot edge 31 by the feeder 48 and is connected to the diametrically opposite slot edge 29 by the feeder 46. The second conductor 38 is connected to the slot edge 30 by the feeder 49 and is also connected to the diametrically opposite slot edge 28 by the feeder 47.

The third and fourth conductors are adapted to energize the upper section 21 against the lower section 22 by feeding across the gap 55. Two diametrically opposite feed points on the gap 55 have been chosen, with the third conductor 39 connected to one point on the upper section 21 by the feeder 50, and connected to a diametrically opposite point on the upper section 21 by the feeder 51. The fourth conductor 40 is in a similar fashion connected to diametrically opposite feed points on the lower section 22 by feeders 52 and 53.

The antenna shown in Figures 1 to 4, inclusive, which is the preferred embodiment of the invention, may be considered as a transducer, as it efficiently transfers energy between free space and an electrical device such as a radio transmitter or receiver. This antenna produces a horizontal field intensity pattern that may be made very nearly circular and hence the gain in the horizontal plane will be substantially uniform. The antenna in its preferred form has a diameter which is only a fraction of a wave length, in the order of $\frac{1}{8}$ a wave length, and hence to use this antenna in the V. H. F. band the diameter will be physically small enough so that the entire antenna will have a low wind resistance. The antenna is a complete entity and needs no ground plane. The

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result being that this antenna is capable of being vertically stacked in any plurality of antennas such as two, four or eight or any other number to flatten the toroidal pattern and hence increase the gain in the horizontal plane.

The slots may be of any practical width and in practice are made sufficiently wide in order to develop the necessary potential difference thereacross without arcing. The slot width is also sufficient to prevent icing or bridging across the slot by sleet formation which would short the slot.

Figure 5 shows another form of antenna which is quite similar to the preferred embodiment of the invention in that the upper and lower sections 21 and 22 still contain first, second, third and fourth vertical slots 33, 34, 35 and 36, and form a horizontal gap 55 therebetween. The method of feeding the antenna shown in Figures 5 and 6 has been accomplished in a different manner however, with first and second coaxial cables 60 and 61, each serving to energize both the vertical slots and the horizontal gap 55. The mast or means to support the antenna shown in Figures 5 and 6 has not been shown for the sake of clarity in the drawing, but it is to be understood that this antenna may be supported in a fashion similar to the method of supporting the preferred embodiment of the invention. The shorting bars 54 which were used in the preferred embodiment of the invention to close the ends of the vertical slots adjacent to the horizontal gap 55 have been removed in the antenna shown in the Figures 5 and 6. The first coaxial cable 60 is shown as being axially aligned with the axis of the antenna and close to the axis thereof in a position such as it would maintain were a mast physically present to support the antenna. Since the coaxial cable method of feeding is an unbalanced form of feeding with respect to ground, the coaxial cable has been electrically connected to the inside of the lower section 22 at a point at least a quarter-wave distance from the feed point. To accomplish this, the coaxial cable 60 has been turned at right angles to its axially aligned direction and extended horizontally outward to the interior wall of the lower section 22 and contacts this interior wall at a point 62. From this point 62 the coaxial cable 60 extends peripherally around and upward to the intersection 56 of the horizontal gap 55 with the second and fourth slots 34 and 36. The outer shell of the coaxial cable 60 terminates at the point 66 of this intersection 56, and the center conductor of the coaxial cable 60 extends across and connects to the diagonally opposite corner 67 of this intersection 56. The second coaxial cable 61 is turned horizontally and extends outward to the inner surface of the lower section 22 at a point 63, from whence it turns and continues peripherally around and upward along the lower section 22 to reach the second intersection 57 of the horizontal gap 55 and the first and third vertical slots 33 and 35. The outer shell of the coaxial cable 61 terminates at the point 64 of this intersection 57, and the inner conductor of the coaxial cable 61 extends across to connect to the diagonally opposite corner 65 of this intersection 57. The line joining the points 62 and 63 is normal to the plane extending through the vertical slots so that symmetry in the feeding of the antenna is maintained.

The effect of feeding diagonally across the 75

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intersections 56 and 57 is to produce an electromagnetic radiated wave that has both a vertical and horizontal component. Such an antenna is capable of producing field intensity patterns in the horizontal plane that are very nearly circular for both the vertically and horizontally polarized waves.

The Figures 7 and 8 show a further modification of the invention wherein a cylinder 71 has two vertical slots for the establishment of horizontally polarized electromagnetic waves which may have a substantially circular field intensity pattern in the horizontal plane. The cylinder 71 has first and second edges 72 and 73 for defining a first vertical slot 82, and third and fourth edges 74 and 75 for defining a second vertical slot 83 that is diametrically opposite the first slot 82. The first and third edges 72 and 74 and the second and fourth edges 73 and 75 are diametrically opposite each other. First and second conductors 76 and 77 are shown as being axially aligned within the cylinder 71, and are spaced relatively close together in relation to their spacing from the cylinder 71 to approximate their position were a mast or some support to be depicted within the cylinder 71. Such a mast or support has been omitted from the Figures 7 and 8 to more clearly show the connections of the feeding arrangement. The first conductor 76 is arranged to be connected to the first and third edges 72 and 74 by feeders 78 and 79 respectively, and the second conductor 77 is arranged to be connected to the second and fourth edges 73 and 75 by feeders 80 and 81 respectively.

Since both slots 82 and 83 are fed from the same pair of conductors, the radiated field of each slot aids the radiation from the other, rather than opposing such radiation. The amplitudes of the radiation from each slot are substantially equal, and hence the horizontal field intensity pattern of horizontally polarized wave is substantially circular. The first and second slots 82 and 83 have been shown as approximately a half wave length long, which is a satisfactory length for the radiation of power, however the slots may be made an effective full wave length in length if desired similar to those shown in Figure 5.

The Figures 9 and 10 show a still further modification of the invention wherein a cylinder 87 has two non-symmetrically placed slots to produce horizontally polarized waves wherein the horizontal field intensity pattern is non-symmetrical about an axis in the horizontal plane. The cylinder 87 has first and second edges 88 and 89 for defining a first vertical slot 92, and third and fourth edges 90 and 91 for defining a second vertical slot 93. The first and second slots 92 and 93 are axially aligned with the cylinder 87 and are spaced 90 physical degrees apart about the periphery of the cylinder 87. First and second conductors 94 and 95 are connected to the first and second slot edges 90 and 91 by first and second feeders 96 and 99 respectively, and third and fourth conductors 96 and 97 are connected to the slot edges 88 and 89 by feeders 100 and 101 respectively.

By using two separate pairs of conductors, one pair to feed each of the two vertical slots 92 and 93, a much greater degree of control over the horizontal field intensity pattern is achieved. Variations in magnitude and phase may easily be accomplished to change the shape of the horizontal field intensity pattern. With two vertical slots in a cylinder, there are four param-

eters to vary to control the field intensity pattern in the horizontal plane. These four parameters are relative magnitude, relative electrical phase, the diameter of the cylindrical antenna in wave lengths, and the peripheral spacing of the slots upon the cylindrical antenna. The graph of Figure 11 shows a horizontal field intensity pattern which the antenna of Figures 9 and 10 is capable of producing. The horizontal field intensity pattern shown in Figure 11 was produced by actual measurements by an antenna similar to that shown in Figures 9 and 10, wherein two vertical slots are spaced 90° apart on the periphery of the cylinder. The first slot was oriented at the 0° radial, and the second slot was oriented at the 270° radial. The diameter of the cylinder was established at one-half wave length, and the feeding was such that the second slot was fed with a magnitude of voltage one-half the magnitude of voltage applied to the first slot, and with the second slot fed 90 electrical degrees advanced in phase.

Figures 12, 13 and 14 show a still further modification of the invention wherein two oppositely rotating spiral slots are fashioned in a hollow cylinder 108. The cylinder 108 is shown as being supported by a mast 109, and is fastened to the mast 109 by supports 110. First and second edges 111 and 112 define a first slot 115, which is a left-hand spiral slot. Third and fourth edges 113 and 114 define a second slot 116, which is a right-hand spiral slot. The first and second spiral slots 115 and 116 are each made one wave length long, and each is inclined 45° to the axis of the cylinder 108. The diameter of the cylinder 108 has been chosen such that each slot 115 and 116 makes one complete revolution about the periphery of the cylinder 108. The supports 110 that fasten the cylinder 108 to the mast 109, are placed at a voltage minimum point of the antenna, which voltage minimum point is produced at points equi-distant from the various slot edges. There are four such points in the antenna as shown in the Figures 12, 13 and 14, and the supports 110 have been located at such voltage minimum points. First and second coaxial cables 117 and 118 are used to feed the first and second slots 115 and 116. These first and second coaxial cables 117 and 118 have been omitted from the perspective view of Figure 12 for the sake of clarity in this view. The first coaxial cable 117 extends through a hole 119 in the mast 109 at a point adjacent to one of the supports 110, and electrically contacts the inner surface of the cylinder 108 at this point. The first coaxial cable 117 then extends upwardly to reach the mid-point 106 of the first spiral slot 115. The outer shell of the coaxial cable 117 ends at the second edge 112, and the inner conductor of the coaxial cable 117 extends across the slot 115 to connect to the first edge 111. A second coaxial cable 118 extends through a hole 120 in the mast 109 adjacent to a support 110 and connects to the inner surface of the cylinder 108. From this point adjacent the support 110 the coaxial cable 118 extends upward vertically to reach the mid-point 107 of the second slot 116. The outer shell of the coaxial cable 118 ends at the fourth edge 114, and the inner conductor of the coaxial cable 118 extends across the second slot 116 to connect to the third edge 113 at the mid-point 107.

The first and second slots 115 and 116 each have a horizontal component and a vertical component, and hence the electromagnetic wave emanating from the spiral slots have both ver-

tical and horizontal components. The horizontal field intensity patterns of both the horizontal and vertically polarized electromagnetic waves of this antenna are very nearly circular.

The antenna shown in Figures 15 and 16 is a simplified version of the antenna shown in Figures 12, 13 and 14, inasmuch as the antenna comprises a cylinder 122 having only one spiral slot. First and second edges 123 and 124 define a slot 125 which has been shown as a left-hand spiral slot. Slot 125 makes a 45° angle with the axis of the cylinder 122. The length of the slot 125 has been made equivalent to one wave length, and the diameter of the cylinder 122 has been chosen such that the slot 125 will complete one revolution about the periphery of the cylinder 122. A coaxial cable 126 is used to feed the slot 125, and is shown as being fastened to the inner surface of the cylinder 122 and axially aligned therewith. The outer shell of the coaxial cable 126 ends at the mid-point 121 of the slot edge 124, and the inner conductor of the coaxial cable 126 extends across the slot 125 to connect to the edge 123 at the mid-point 121. A novel feature of the antenna shown in Figures 15 and 16 is that the cylinder 122 needs no separate support, the cylinder 122 may support itself. The slot 125 in the cylinder 122 simulates a slot formed in a hollow flag pole like structure.

Satisfactory radiation may be obtained from the antenna shown in Figures 15 and 16, and substantially circular horizontal field intensity patterns of both the horizontal and vertically polarized waves may be attained.

The slot 125 in the cylinder 122 of Figures 15 and 16 may have some form of insulator across this slot to strengthen the entire antenna structure. Such an insulator may be a conduit insulator covering the entire slot or may be one or more segments extending across at any plurality of points on the slot 125. Likewise insulators may be placed across the slots 115 and 116 in the antenna shown in Figures 12, 13 and 14.

The antenna shown in Figures 17 and 18 shows a fragment of a two slot cylindrical antenna wherein inwardly turned lips 128 are provided on the vertical slot 129 to increase the capacity across this vertical slot. By increasing the capacity across the vertical slots, the impedance across the slot is changed and hence such lips may be used to obtain a correct impedance match between the transmission line and the slots in the cylinder. By experiment, it has been found that the size or effective area of these lips is the controlling factor so the result obtained therefrom is attributable to capacity.

The Figures 19 and 20 show a cylinder 130 having two vertical slots 131 and a horizontal gap 132. The horizontal gap 132 has been provided with capacity disks 133 which extend horizontally from the edges of the cylinder that form the horizontal gap 132. The capacity disks 133 are not continuous, each being formed substantially in halves so that the vertical slots 131 are not closed by the capacity disks 133. The capacity disks 133 perform a function similar to the lips 128 shown in Figures 17 and 18, in that they increase the capacity across the horizontal gap 132. By so increasing the capacity, the impedance is changed, and more energy is passed between the upper and lower sections of the cylindrical antenna 130. The antenna shown in Figures 19 and 20 is similar

to that shown in the preferred embodiment shown in Figures 1, 2, 3 and 4 and is similar to the modified form shown in Figures 5 and 6. The antenna shown in Figures 5 and 6, since it is fed diagonally across the juncture of the horizontal gap and the vertical slot, depends upon equal impedance of the vertical slots and horizontal gap to produce substantially equal horizontal and vertical radiation. The capacity disks 133 have been used to advantage to increase the horizontally polarized radiation, in that by increasing the capacity between the upper and lower sections of the entire antenna, more energy is available across the vertical slots in both the upper and lower sections, hence horizontal radiation is increased.

Figures 21 and 22 show a still further modification wherein outwardly turned lips 134 are connected to the edges of the vertical slots 135 of the slotted cylindrical antenna 136. Capacity disks 137 are connected to the edges of a horizontal gap 138 at the longitudinal center of the antenna 136. The lips 134 have been shown as outwardly turned rather than as inwardly turned such as the lips 128 of Figure 17, to illustrate that the capacity effect of the lips 134 is the prime factor, and not the direction of deflection. By combining the vertical lips 134 and the horizontal capacity disks 137 the impedance of both vertical slot 135 and horizontal gap 138 may be changed to produce the correct impedance match desired in any particular application. Such changes of impedance may be utilized to advantage with a feed system similar to that shown in the antenna of Figures 5 and 6, wherein the feed is diagonally across the juncture of the vertical slot and the horizontal gap.

As shown in Figures 21 and 22 the capacity lips 134 need not be made the same radial length as the radial length of the capacity disks 137, the radial length of each determining the effective area and hence the capacity desired to obtain the correct impedance match of the respective vertical slot or horizontal gap.

The Figure 23 shows a sectional view in perspective of a slotted cylindrical antenna 142 being carried by a mast 143 by means of supports 144. Edges 140 define two vertical slots 139. Fins 141 are connected to each of the edges 140 and extend inwardly toward the mast 143 for approximately half the radial distance between the antenna 142 proper and the mast 143, then deviate to extend peripherally around the mast 143 and substantially parallel therewith. The effect of the fins 141 is to increase the dimensions of the cavity behind the vertical slot 139 since the current flows on the surface of the antenna 142, and the total surface is increased by the fin 141 being placed inside the cavity behind the slot 139.

The fins 141 are helpful to control the impedance of the slots 139 since they may be caused to produce standing waves on the surface of the antenna 142 and since they effectively increase the dimensions of the cavity in wave lengths without changing the diameter of the antenna 142. By proper designing of the dimensions of the fins 141, control of the driving point impedance may be effected.

Although the invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combina-

tion and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

1. A transducer for transferring electromagnetic wave energy between free space and an electrical device utilizing said electromagnetic waves, said transducer comprising electrically conducting conduit means, at least first and second substantially parallel edges in said conduit means for defining slot means therein, said slot means having a narrow width relative to the length thereof, said slot means having a lengthwise dimension with a component aligned parallel to the axis of said conduit means, a single slot in said slot means having a lengthwise dimension with a transverse component extending substantially completely around said conduit means, at least part of said conduit means defining a single dielectric-filled cavity for said slot means and transmission line means connected across each slot in said slot means.

2. An antenna for circularly polarized electromagnetic waves of a given wave length with a substantially circular horizontal field intensity pattern, said antenna comprising electrically conducting conduit means, means for mounting said conduit means with the axis thereof in a vertical position, first and second substantially parallel edges in said conduit means for defining a first slot, third and fourth substantially parallel edges in said conduit means for defining a second slot, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, each of said slots having a length at least equal to a half of said given wave length, first feed means within the confines of said conduit means connected across at least the center of each of said slots, fifth and sixth substantially parallel edges in said conduit means for defining a third slot with the lengthwise dimension substantially extending about the periphery of said conduit means in a plane normal to the axis thereof, and second feed means within the confines of said conduit means connected across the edges of said third slot.

3. An antenna for circularly polarized electromagnetic waves of a given wave length with a substantially circular horizontal field intensity pattern, said antenna comprising electrically conducting conduit means, means for mounting said conduit means with the axis thereof in a vertical position, first and second substantially parallel edges in said conduit means for defining a first slot, third and fourth substantially parallel edges in said conduit means for defining a second slot, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, each of said slots having a length at least equal to a half of said given wave length, first feed means within the confines of said conduit means connected across at least the center of the edges of each of said slots, fifth and sixth substantially parallel edges in said conduit means for defining a third slot with the lengthwise dimension substantially extending about the periphery of said conduit means in a plane normal to the axis thereof, second feed means within the confines of said conduit means connected across the edges of said third slot, said first and second feed means including first, second, third and fourth substantially parallel conductors substantially axially parallel with said conduit means, said first feed means including first and second feeder lines extending substantially horizontally to connect the center of each of said

first and third edges to said first conductor and third and fourth feeder lines to connect the center of each of said second and fourth edges to said second conductor, and said second feed means including fifth and sixth feeder lines extending substantially horizontally to connect said fifth and sixth edges to said third and fourth conductors, respectively.

4. An antenna for circularly polarized electromagnetic waves of a given wave length with a substantially circular horizontal field intensity pattern, said antenna comprising electrically conducting conduit means, means for mounting said conduit means with the axis thereof in a vertical position, first and second substantially parallel edges in said conduit means for defining a first slot, third and fourth substantially parallel edges in said conduit means for defining a second slot, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, each of said slots having a length at least equal to a half of said given wave length, fifth and sixth substantially parallel edges in said conduit means for defining a third slot with the lengthwise dimension substantially extending about the periphery of said conduit means in a plane normal to the axis thereof, first and second feed means within the confines of said conduit means, said first and third slots defining a first juncture and said second and third slots defining a second juncture, said first and second feed means including first and second coaxial cables, means for connecting the diagonally opposite corners of said first juncture to the respective two conductors of said first coaxial cable, and means for connecting the diagonally opposite corners of said second juncture to the respective two conductors of said second coaxial cable.

5. An antenna comprising electrically conducting conduit means having an axis, first and second substantially parallel edges in said conduit means for defining a first slot, third and fourth substantially parallel edges in said conduit means for defining a second slot, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, each of said slots having a length at least equal to a half of said given wave length, fifth and sixth substantially parallel edges in said conduit means for defining a third slot with the lengthwise dimension substantially extending about the periphery of said conduit means in a plane normal to the axis thereof, and transmission line means within the confines of said conduit means connected across the center of each of said first and second slots and connected across the edges of said third slot.

6. An antenna comprising electrically conducting conduit means having an axis, first and second substantially parallel edges in said conduit

means for defining a first axially parallel slot, said slot having a length at least equal to a half of said given wave length, third and fourth substantially parallel edges in said conduit means for defining a second slot with the lengthwise dimension extending substantially completely around the periphery of said conduit means in a plane substantially normal to the axis thereof, and transmission line means within the confines of said conduit means connected across the center of said first slot and connected across the edges of said second slot.

7. An antenna comprising electrically conducting conduit means having an axis, a plurality of substantially parallel edges in said conduit means for defining a plurality of slots, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, each of said slots having a length at least equal to a half of said given wave length, additional substantially parallel edges in said conduit means for defining a transverse slot with the lengthwise dimension substantially extending about the periphery of said conduit means in a plane substantially normal to the axis thereof, and transmission line means within the confines of said conduit means connected across the center of each of said axially parallel slots and connected across the edges of said transverse slot.

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