

Jan. 5, 1954

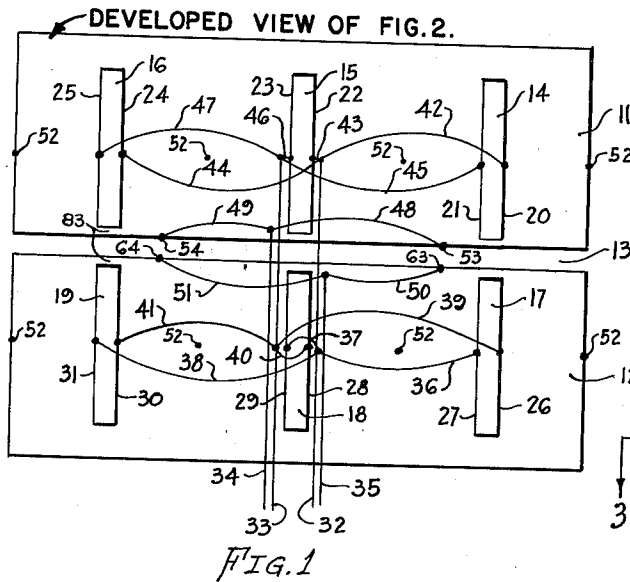
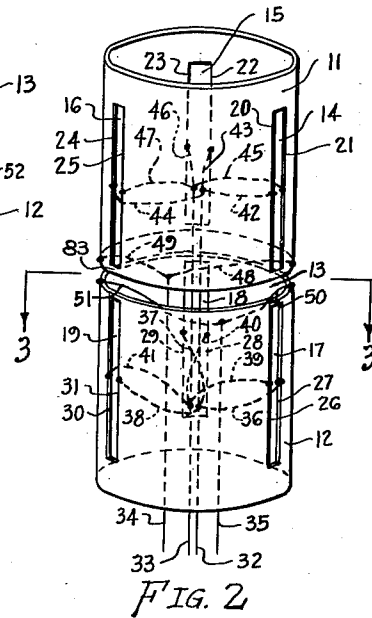
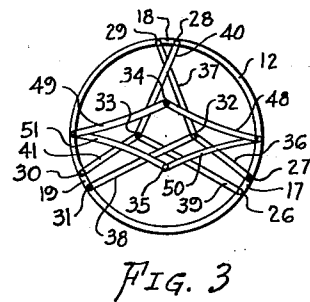
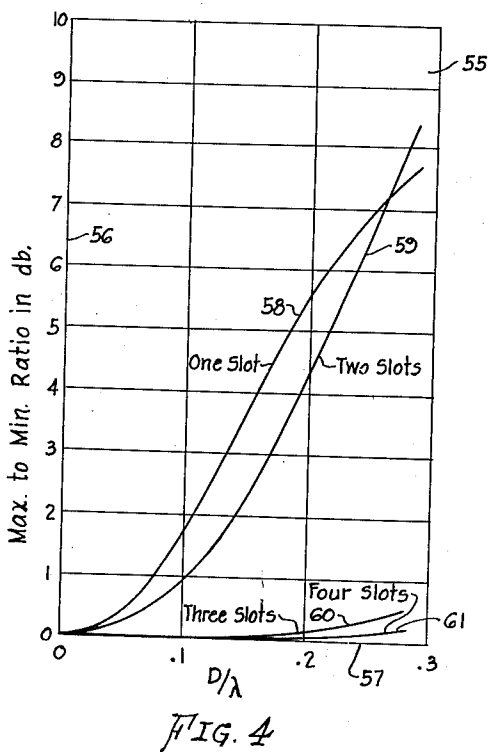
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2,665,382

THREE SLOT CYLINDRICAL ANTENNA

Filed Oct. 16, 1947

3 Sheets-Sheet 1



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THREE SLOT CYLINDRICAL ANTENNA

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3 Sheets-Sheet 2

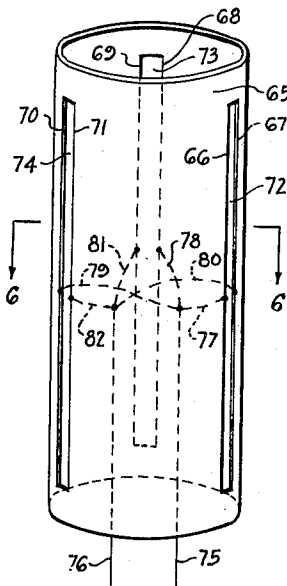


FIG. 5

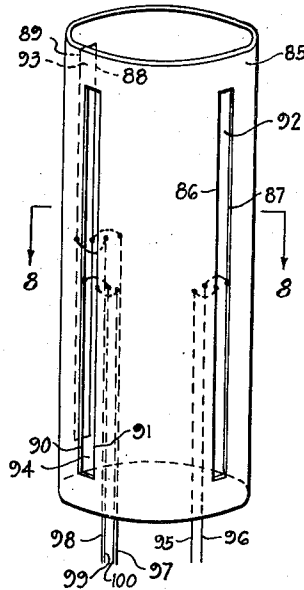


FIG. 7

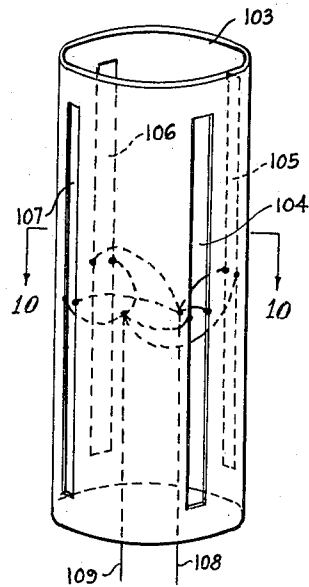


FIG. 9

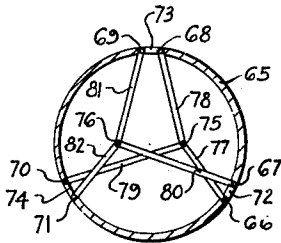


FIG. 6

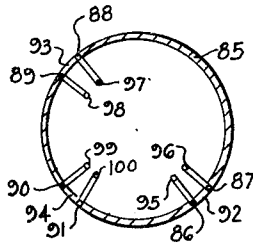


FIG. 8

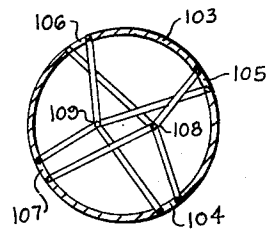


FIG. 10

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THREE SLOT CYLINDRICAL ANTENNA

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3 Sheets-Sheet 3

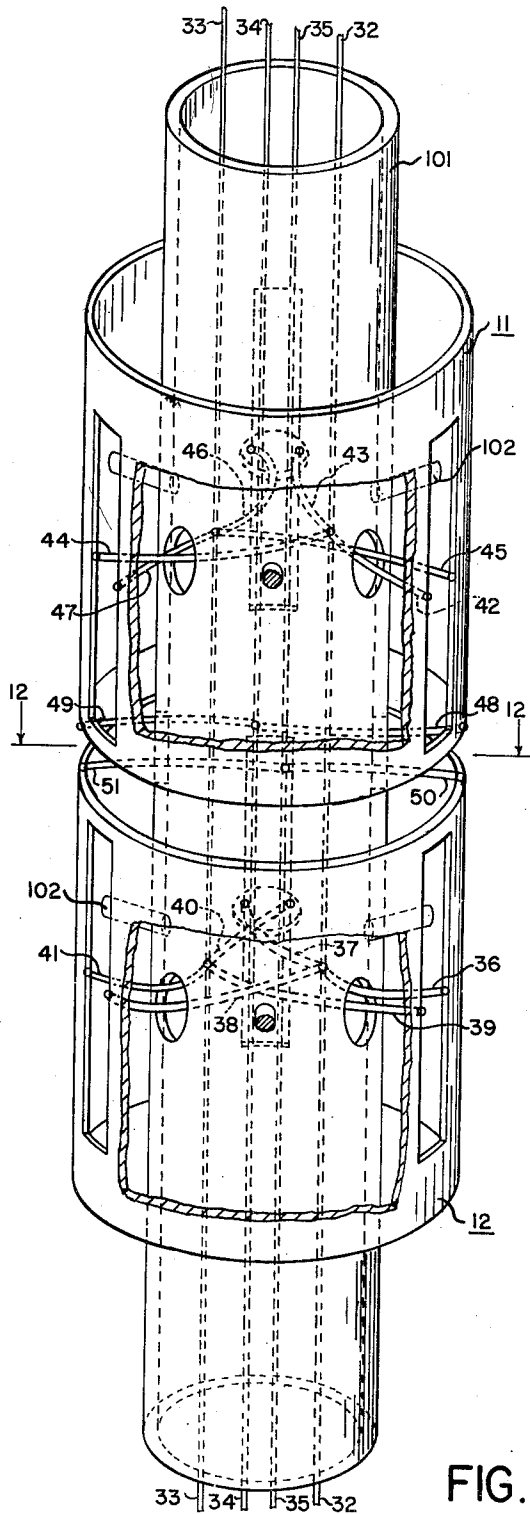
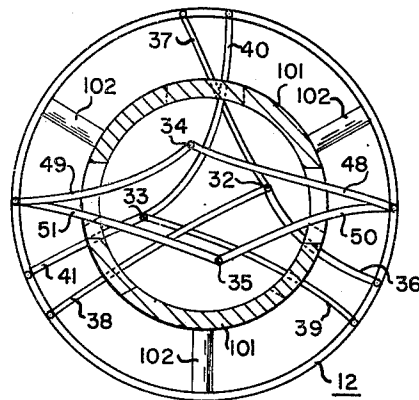


FIG. 12

FIG. 11

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UNITED STATES PATENT OFFICE

2,665,382

THREE SLOT CYLINDRICAL ANTENNA

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Application October 16, 1947, Serial No. 780,265

7 Claims. (Cl. 250—33)

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The invention relates in general to antennas for use with electromagnetic wave energy, and in particular to conduits or hollow cylinders having at least three slots therein for the radiation of energy.

An object of the invention is to provide an antenna having a high gain in the horizontal plane and with a considerable degree of control of the horizontal field intensity pattern.

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 minimum points and/or circularity.

A further object of the invention is to provide a hollow cylindrical antenna having at least three 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 waves with a high uniform gain in the horizontal plane.

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

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;

Figure 2 is a perspective view of the preferred embodiment of the invention;

Figure 3 is a cross sectional view taken along with line 3—3 of Figure 2;

Figure 4 is a graph of the diameter of the cylinder plotted in wave lengths against the ratio of the maximum to minimum db on the horizontal field intensity patterns for antennas of one, two, three and four slots when the slots are fed with equal power and phase;

Figure 5 is a perspective view of a modification of the invention;

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

Figure 7 is a perspective view of another modification of the invention;

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

Figure 9 is a perspective view of a still further modification of the invention;

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

Figure 11 is an isometric view of the preferred embodiment of the invention similar to that shown in Figure 2 with a supporting mast also being shown; and

Figure 12 is a sectional view taken on the line 12—12 of Figure 11.

The invention deals with antennas that have three or more slots in a conduit, which conduit has been shown in the drawings and is preferably in the form of a hollow cylinder for use in producing circular horizontal patterns.

For fundamental concepts of the invention, reference may be had to the co-pending application filed concurrently herewith, entitled "Slotted Cylindrical Antennas," Serial No. 780,264.

The preferred embodiment of the invention is shown in Figures 1 to 3, and in the enlarged views of Figures 11 and 12, and shows hollow cylindrical upper and lower sections 11 and 12. These upper and lower sections 11 and 12 are adapted to be supported by an internal structure or mast, which has not been shown in the Figures 1, 2 and 3 of the drawings for the sake of clarity. A novel feature of the invention resides in the fact that the antenna may be supported entirely from within the confines of the conduit or hollow cylinder, no external physical structure is required. The Figure 1 is a developed view showing the hollow cylindrical upper and lower sections 11 and 12 cut open and laid into a flat sheet in order to more clearly show the connections. The upper section 11 has first and second edges 20 and 21 for defining a first slot 14, third and fourth edges 22 and 23 for defining a second slot 15, and fifth and sixth edges 24 and 25 for defining a third slot 16. The first, second and third slots 14, 15 and 16 are symmetrically placed about the periphery of the cylindrical upper section 11, and are axially parallel therewith. The first, third and fifth edges 20, 22 and 24 are symmetrically spaced. In a similar manner the lower section 12 has seventh and eighth edges 26 and 27 for defining a fourth slot 17, ninth and tenth edges 28 and 29 for defining a fifth slot 18, and eleventh and twelfth edges 30 and 31 for defining a sixth slot 19. The fourth, fifth and sixth slots 17, 18 and 19 are vertical and axially parallel with the conduit and are symmetrically spaced on the periphery of the lower section 12. The seventh,

ninth and eleventh edges 26, 28 and 30 are symmetrically spaced on the periphery, and the eighth, tenth and twelfth edges 27, 29 and 31 are also symmetrically spaced on the periphery. The fourth, fifth and sixth slots 17, 18 and 19 are spaced adjacent the first, second and third slots in the upper section 11. The first, second, third, fourth, fifth and sixth slots 14 to 19, inclusive, serve as a means to radiate the electromagnetic wave energy, and in this preferred embodiment of the invention are shown as being approximately a half wave length long. The upper and lower sections 11 and 12 are each made a half wave length long for convenience in vertically stacking duplicates of this antenna to increase the horizontal gain, however, the length of the cylindrical upper and lower sections 11 and 12 is not a pertinent factor to determine the radiation efficiency.

The upper and lower sections 11 and 12 are spaced apart and form a horizontal gap 13 which has in practice been made approximately equal to the width of the vertical slots. The vertical slots, which are shown as being a half wave length, are caused to be closed by shorting bars 83 at the end adjacent the horizontal gap 13. These shorting bars cause the vertical slots in each of the upper and lower sections to be approximately a half wave length, which is an efficient length for the radiation of energy. The shorting bars may be omitted in some applications, since according to transmission line theory, a short at one point effectively produces a short a half wave length away, so the slots being closed at one end and open at the other may prove satisfactory as an impedance match in any particular application without the use of such shorting bars.

The upper and lower sections 11 and 12 may be fastened to an internal support or mast 101 at points 52 which are voltage minimum points, as shown in Figures 11 and 12. These points 52 are in the geometric center of the periphery between adjacent slot edges. Electrically conducting supporting arms 102 may be used to connect the antenna to an electrically conducting internal support or mast which may be grounded. This effectively grounds the geometric center points 52, which is not harmful since these points 52 will be the voltage minimum point on the antenna proper.

First, second, third and fourth axially aligned parallel conductors 32, 33, 34 and 35 are provided within the confines of the antenna to connect the antenna to some electrical device such as a transmitter or a receiver. The first and second conductors 32 and 33 are adapted to feed the vertical slots and the third and fourth conductors are adapted to feed the horizontal gap 13. By energizing the vertical slot horizontal polarization of the radiated wave is effected, and by energizing the horizontal gap 13, which is exciting the upper section 11 against the lower section 12, vertical polarization of the radiated wave is effected. By establishing these two planes of radiation in 90° time phase displacement, elliptical polarization of the radio wave is effected. By adjusting the amplitude of the horizontal and vertical components equally the elliptically polarized wave becomes circularly polarized. The upper and lower sections 11 and 12 that effect vertically polarized radiation establish a substantially circular field intensity pattern in the horizontal plane, since this structure is akin to a fat dipole. The vertical slots in the upper and

lower sections 11 and 12 radiate horizontally polarized electromagnetic waves with the field intensity pattern in the horizontal pattern substantially circular. The result of the combination of the circular horizontal field intensity patterns of both vertically and horizontally polarized waves gives a substantially uniform gain in the horizontal plane with a substantially circularly polarized electromagnetic wave if the two planes of polarization are fed in 90° time phase displacement.

The first and second conductors 32 and 33 are connected to the vertical slots by short horizontal feeder lines. The first conductor 32 is connected to the slot edges 20, 22 and 24 by feeders 42, 43 and 44, respectively. The second conductor 33 is connected to the slot edges 21, 23 and 25 by feeders 45, 46 and 47. These feed connections are at the center of the respective slot edges in the upper section 11. The same first and second conductors 32 and 33 feed the vertical slots in the lower section 12, the feed point for these slots being at the center thereof, which is substantially one half wave length below the feed point for the vertical slots in the upper section 11. Since the feed point for the vertical slots in the lower section 12 is one half wave length distant from the feed point of the vertical slots in the upper section 11, the feeding connections are reversed in order to make the polarity emanating from the vertical slots of both sections reinforce rather than oppose each other. To feed the vertical slots in the lower section 12, the second conductor 33 is connected to the slot edges 26, 28 and 30 by feeders 39, 40 and 41, respectively, and the first conductor 32 is connected to the slot edges 27, 29 and 31 by feeders 36, 37 and 38, respectively.

The third and fourth conductors 34 and 35 are adapted to energize the upper section 11 against the lower section 12 by feeding across the horizontal gap 13. Two diametrically opposed feed points on the gap 13 have been chosen merely as a matter of convenience. Any number of feed points may be used when the shorting bars 83 are used, the greater the number the lower the possibility of phase displacement of vertically polarized wave emanating from different positions of the antenna. If shorting bars 83 are not used, three feed points, or multiples thereof, must be used in order to feed all sections of the periphery equally. The third conductor 34 is connected to diametrically opposite points 53 and 54 on the upper section 11 by horizontal feeders 48 and 49, respectively. The fourth conductor 35 is in a similar fashion connected to diametrically opposite points 63 and 64 on the lower section 12 by horizontal feeders 50 and 51, respectively. The points 53 and 63 are adjacent each other across the horizontal gap 13, and likewise the feed points 54 and 64 are adjacent each other across the horizontal gap 13.

The antenna shown in Figures 1 to 3, inclusive, and Figures 11 and 12, which is the preferred embodiment of the invention, may be considered as a transducer in conjunction with a receiver or transmitter. 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. Each vertical slot which effects radiation of power needs no cooperation from any other slot and hence an electrically conducting tower or mast 101 may be placed within the conduit or hollow cylinder. Such a supporting tower would

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act as a shield if of electrically conducting material and hence if any slot depended on cooperation with any other slot to produce satisfactory radiation such a shield would destroy such cooperation. The result being that this antenna is capable of being vertically stacked with other similar duplicate antennas to increase the horizontal gain and the supporting tower or mast may extend axially within the confines of all such plurality of antennas.

This antenna represents an improvement over the slotted cylindrical antennas shown in the co-pending application entitled "Slotted Cylindrical Antennas" in that with three or more slots the circularity of the horizontal field intensity pattern is greatly increased. With all vertical slots fed in a phase displacement to reinforce each other the horizontally polarized waves produce a very nearly circular horizontal field intensity pattern. If the maximum and minimum field strength points of such a horizontal pattern are converted to a maximum to minimum ratio and expressed in db and such a ratio is plotted as the vertical scale 56 against a horizontal scale 57 of the diameter of the cylinder in wave lengths, the curves may be plotted on a graph 55 such as is shown in Figure 4. Figure 4 shows such curves plotted for antennas of from one to four slots 58, 59, 60 and 61, respectively. It will be noted that the curves 58 and 59 for cylinders of one slot and two slots rise much more quickly and steeply than do the curves 60 and 61 of cylinders for three and four slots, respectively. The Figure 4, therefore, shows that the circularity of the horizontal field intensity pattern degenerates rapidly with increasing diameter for one and two slot cylinders, yet the circularity of the horizontal pattern for three and four slot cylindrical antennas does not degenerate nearly as rapidly. This new and unexpected result obtained by three and four slot antennas is a basis for the invention in this instant application.

Figures 5 and 6 show another form of antenna having three symmetrically placed vertical slots to effect a horizontal pattern of horizontally polarized electromagnetic waves which is very nearly circular. The antenna of Figures 5 and 6 shows a cylinder 65 which has been shown as having a length approximately equal to one wave length. First and second edges 66 and 67 define a first slot 72, third and fourth edges 68 and 69 define a second slot 73, and fifth and sixth edges 70 and 71 define a third slot 74. The first, second and third slots 72, 73 and 74 are vertical and axially aligned with the cylinder 65. These vertical slots have been shown as being approximately .9 or .95 wave length long so that they are effectively a full wave length long in relation to the effective velocity of propagation of the electromagnetic wave along the cylinder 65. A supporting tower or mast may be used to support the cylinder 65 from within, and such a supporting tower has not been shown in the Figures 5 and 6 for the sake of clarity in showing the feeding connections. First and second substantially parallel axially aligned conductors 75 and 76 are adapted to energize the midpoints of the vertical slots to effect radiation therefrom or to be receptive to radiant energy. The first conductor 75 is connected to the midpoint of the slot edges 66, 68 and 70 by short horizontal feeders 77, 78 and 79. The second conductor 76 is connected to the midpoint of the slot edges 67, 69 and 71 by the short horizontal feeders 80, 81 and 82. Since all three vertical slots 72, 73 and 74 are fed in phase, the radiation from each slot reinforces the radiation from

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the others, and hence a very nearly circular horizontal field intensity pattern is produced.

Figures 7 and 8 show a further modification of the invention wherein a cylinder 85, which is approximately a full wave length long, has three non-symmetrically placed vertical slots to establish horizontal patterns of the horizontally polarized wave which may be made non-symmetrical about any or all axes in the horizontal plane. The cylinder 85 has first and second edges 86 and 87 defining a first slot 92, third and fourth edges 88 and 89 defining a second slot 93, and fifth and sixth edges 90 and 91 defining a third slot 94. These slots 92, 93 and 94 are vertical and axially aligned with the cylinder 85 and these slots have been placed on the periphery thereof such that the first and second slots 92 and 93 are diametrically opposite each other and the third slot 94 is spaced 90° therebetween on one half of the periphery of the cylinder 85.

In order to obtain the maximum flexibility of control three separate pairs of parallel line conductors are provided, one pair for feeding each of the three slots. First and second conductors 95 and 96 are connected to the midpoints of the edges 86 and 87, respectively, third and fourth conductors 97 and 98 are connected to the midpoints of the third and fourth slot edges 88 and 89, and fifth and sixth conductors 99 and 100 are connected to the midpoints of the fifth and sixth slot edges 90 and 91.

By using separate pairs of conductors to feed each vertical slot, the relative magnitude and relative phase of the energy applied to each slot may be varied. This antenna having three non-symmetrically placed vertical slots has seven parameters capable of being varied to produce thousands of different horizontal field intensity patterns. These seven parameters include two for relative magnitudes of each of the three pairs of slots, two parameters for the relative phase between the three pairs of slots, two parameters for the relative peripheral spacing between the three pairs of slots, and the parameter of the diameter of the cylinder in wave lengths. By having seven parameters, the horizontal pattern is highly controllable as to minimum points and/or lobes of high gain.

Figures 9 and 10 show a still further modification of the invention wherein a cylinder 103 has four symmetrically placed longitudinal slots about the periphery thereof. This antenna is similar to the three slot symmetrical antenna shown in Figures 5 and 6 except that a fourth slot has been added to increase the circularity of the horizontal field intensity pattern. The cylinder 103 has a plurality of vertical edges for defining first, second, third and fourth vertical and axially aligned slots 104, 105, 106 and 107. First and second axially aligned parallel conductors 108 and 109 are provided to energize these four vertical slots. The first conductor 108 energizes one side of each of the four vertical slots in parallel and the second conductor energizes the remaining four edges of the four vertical slots. Since the four slots are all energized in phase, the radiated energy from each slot reinforces radiation from the other slots and hence the horizontal pattern is very nearly circular.

The curve 61 in Figure 4 depicts the maximum to minimum ratio in db plotted against the diameter of the cylinder in wave lengths and hence this curve 61 shows that such a horizontal pattern of a four slot symmetrical cylindrical an-

tenna departs from a true circle only by minute irregularities.

All the slotted cylindrical antennas of the instant application may be stacked to increase the gain in the horizontal plane since each may be internally supported and such an internal support may be an electrical shield without affecting the radiation pattern.

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

We claim as the invention:

1. 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, fifth and sixth substantially parallel edges in said conduit means for defining a third slot, said slots being substantially vertical 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, seventh and eighth substantially parallel edges in said conduit means for defining a fourth slot extending about the periphery of said conduit means with said seventh and eighth edges lying in planes substantially normal to the axis of said conduit means, and transmission line means within the confines of said conduit means connected across the center of said first, second and third slots and connected across the edges of said fourth slot.

2. An antenna for radiating 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, fifth and sixth substantially parallel edges in said conduit means for defining a third slot, said slots being substantially vertical and equally spaced on the periphery of said conduit means, said conduit means defining a common conductive walled cavity for said slots, 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, seventh and eighth substantially parallel edges in said conduit means and lying in planes substantially perpendicular to said axis for defining a fourth slot extending about the periphery of said conduit means, second feed means within the confines of said conduit means connected across the edges of said fourth slot, said first and second feed means including, first, second, third, and fourth substantially parallel conductors substantially parallel to said conduit means, said first feed means including, first, second and third feeder lines extending

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

3. An antenna for circularly polarized electromagnetic waves with a substantially circular horizontal field intensity pattern, said antenna comprising electrically conducting conduit means, 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, fifth and sixth substantially parallel edges in said conduit means for defining a third slot, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, said conduit means defining a common conductive walled cavity for said slots, first feed means connected across at least the center of each of said slots, seventh and eighth substantially parallel edges in said conduit means for defining a fourth slot with the lengthwise dimension substantially extending about the periphery of said conduit means, and second feed means connected across the edges of said fourth slot.

4. An antenna for circularly polarized electromagnetic waves with a substantially circular horizontal field intensity pattern, said antenna comprising electrically conducting conduit means, 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, fifth and sixth substantially parallel edges in said conduit means for defining a third slot, said slots being substantially axially parallel and equally spaced on the periphery of said conduit means, said conduit means defining a common conductive walled cavity for said slots, first feed means connected across at least the center of each of said slots, seventh and eighth substantially parallel edges in said conduit means for defining a fourth slot with the lengthwise dimension substantially extending about the periphery of said conduit means, and second feed means within the confines of said conduit means connected across the edges of said fourth slot, said first and second feed means including first, second, third, and fourth substantially parallel conductors substantially parallel to said conduit means.

5. An antenna comprising, electrically conducting conduit means having an axis, at least three pairs of substantially parallel edges in said conduit means defining at least three slots, said three slots comprising slot means, said three slots having a lengthwise dimension with a component axially parallel, said slot means having a lengthwise dimension with a component transverse to the axis of said conduit means and extending substantially completely around the periphery of said conduit means, each of said slots having a length at least equal to a half of said given wave length, and transmission line means within the confines of said conduit means connected to the edges of said slots.

6. An antenna comprising, electrically conducting conduit means having an axis, at least three pairs of substantially parallel edges in said conduit means defining at least three substantially

axially parallel slots, each of said slots having a length at least equal to a half of said given wave length, another pair of substantially parallel edges in said conduit means for defining a fourth slot with a lengthwise dimension extending substantially completely around the periphery of said conduit means with said another pair of edges lying in planes substantially normal to the axis of said conduit means, and transmission line means within the confines of said conduit means connected across the center of said axially parallel slots and connected across the edges of said fourth slot.

7. An antenna comprising, electrically conducting conduit means having an axis, a plurality of substantially parallel edges in said conduit means for defining at least three 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 fourth slot extending about the periphery of said conduit means with said additional edges lying in planes substantially normal to the axis of said conduit means, and transmission line means within the confines of said conduit means connected across the center of

said axially parallel slots and connected across the edges of said fourth slot.

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