May 15, 1956 R. M. SPRAGUE 2,746,039

ANTENNA

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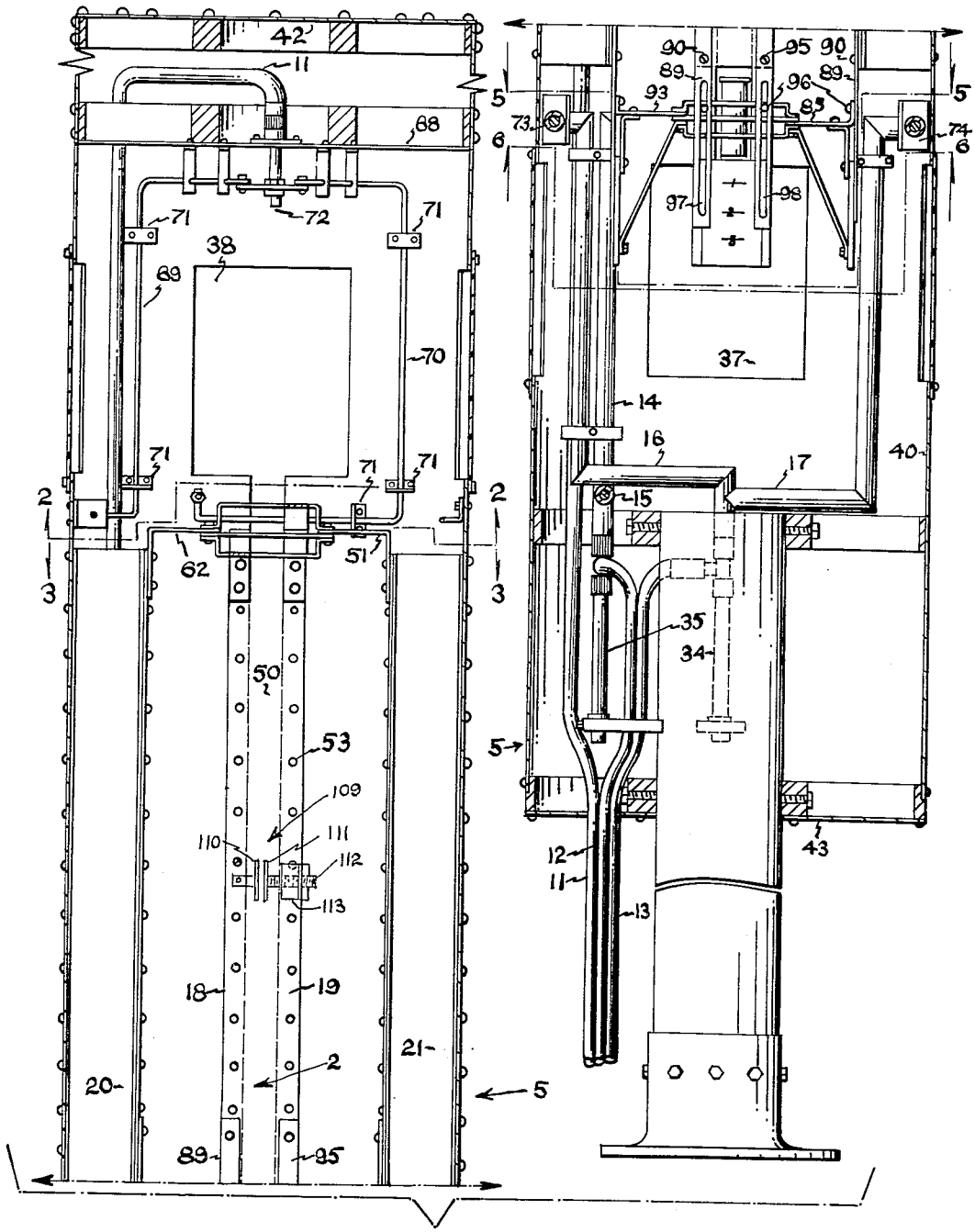


FIG. 1

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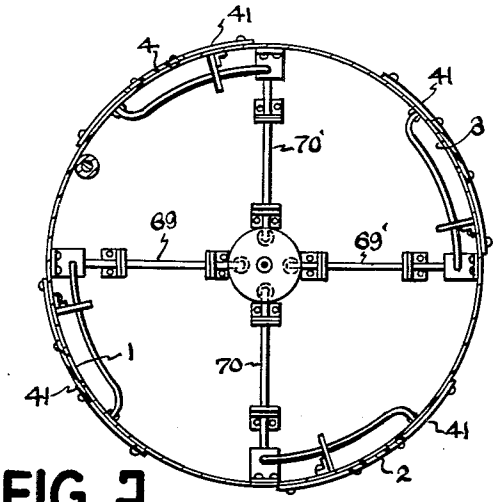


FIG. 2

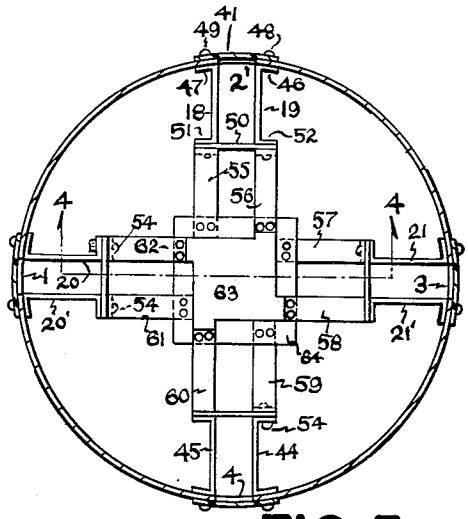


FIG. 3

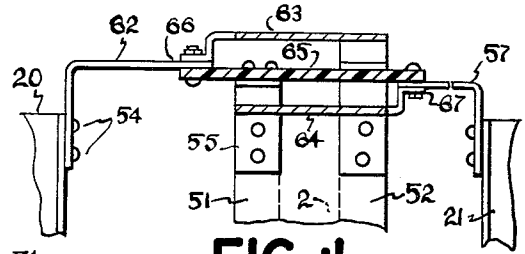


FIG. 4

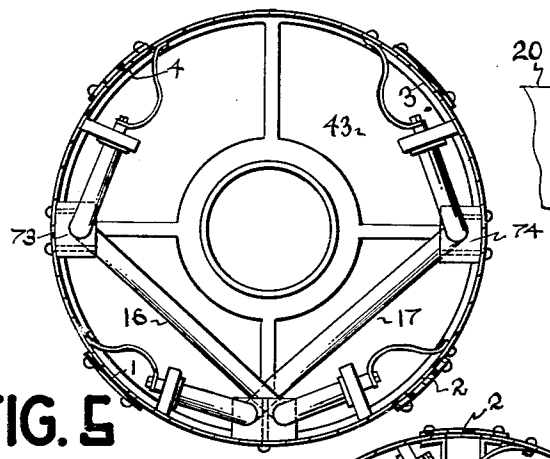


FIG. 5

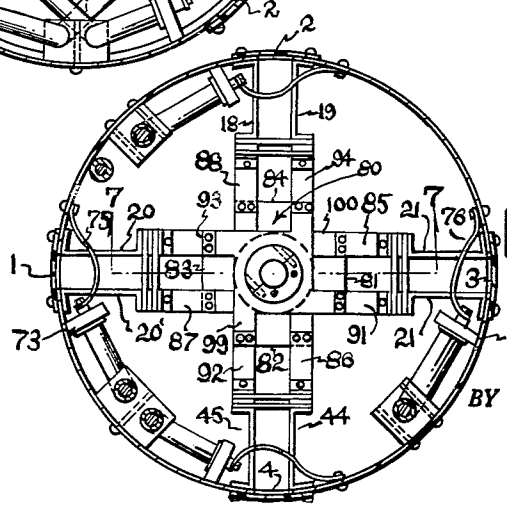


FIG. 6

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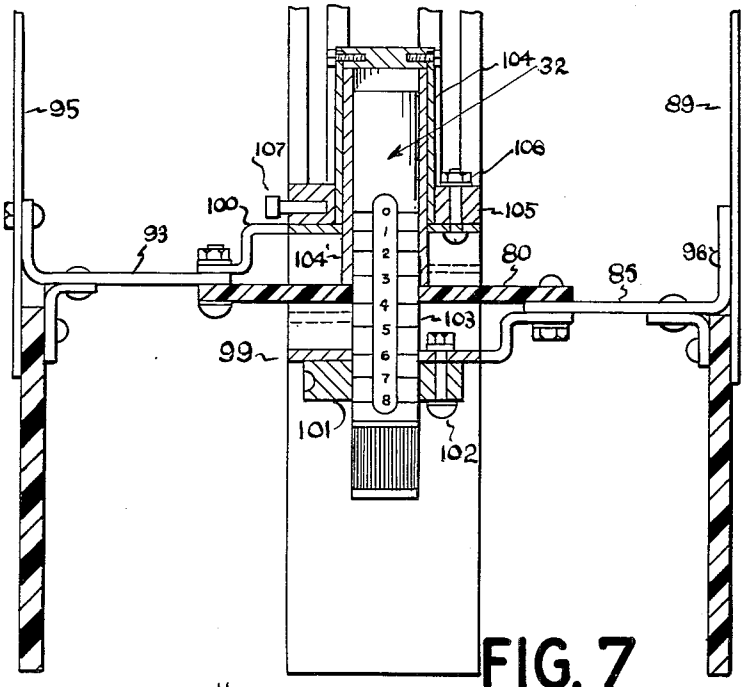


FIG. 7

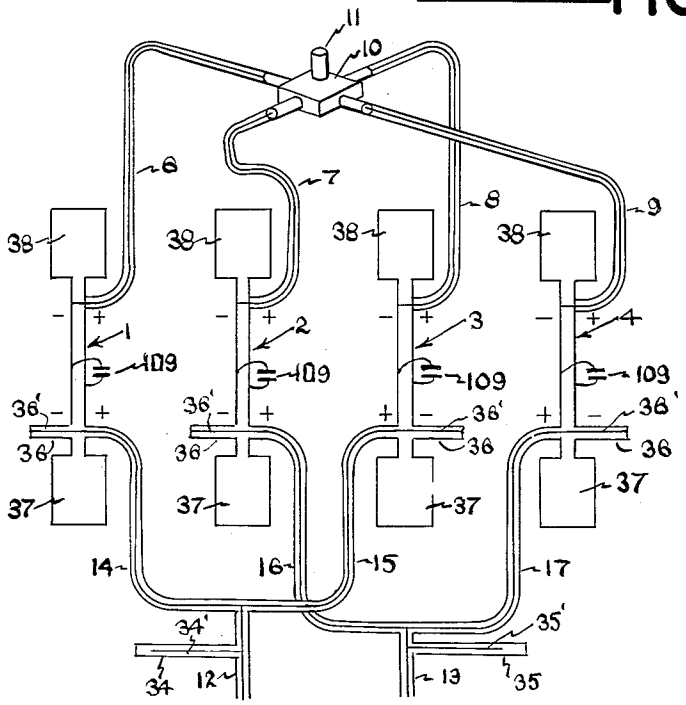


FIG. 8

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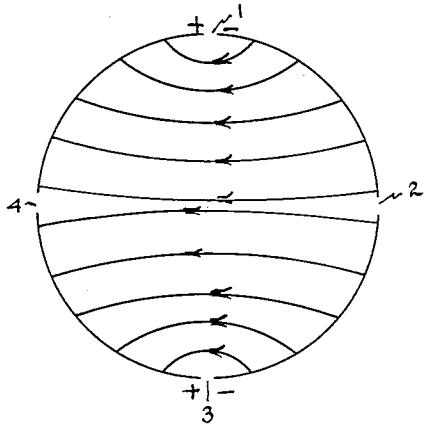


FIG. 9b

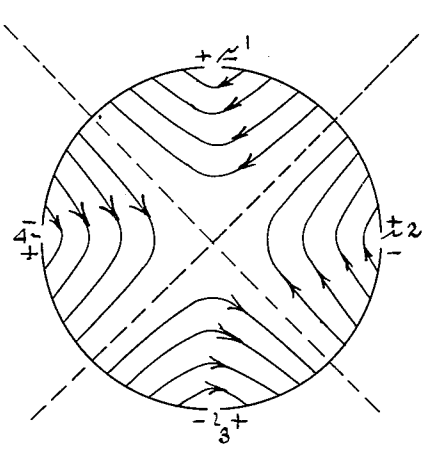


FIG. 9a

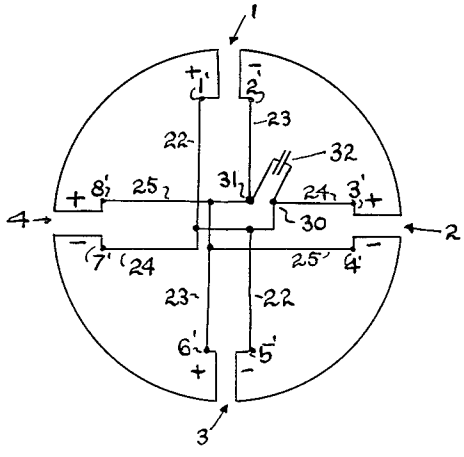


FIG. 10a

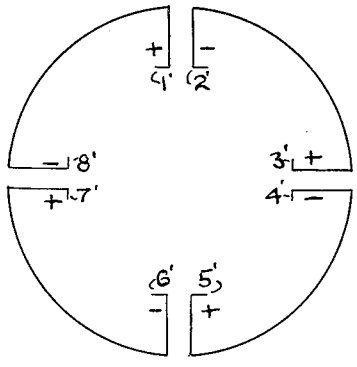


FIG. 10b

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2,746,039

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Application April 28, 1952, Serial No. 284,680

14 Claims. (Cl. 343—767)

The present invention relates to omni-directional range antenna and to means and method of producing with a single antenna structure a circular or reference radiation pattern and two side band of figure-of-eight patterns having axes of symmetry coinciding with that of the circular pattern.

The omni-directional range antenna of the present invention consists essentially of a cylindrical slotted antenna wherein four longitudinal slots which form the radiating elements are spaced equally about the cylinder. The radiation from the slots is horizontally polarized. In operation the antenna is stationary, a rotating pattern being obtained by the use of a goniometer. The same structure is used for both the reference or circular pattern and for the two side band or figure-of-eight patterns. Thus the source of radiation is the same for all signals, resulting in equal phase and amplitude at any point in space.

In the present application, a cylindrical structure for the most part will be referred to, but it is to be noted that the invention contemplates the use of other equivalent forms and shapes by which the same results may be obtained, as for instance, a polygon, oval or other type of structure wherein both the circular and figure-of-eight radiation patterns may be obtained.

In the present invention the antenna is fed by unbalanced or balanced lines across four slots. When all four slots are excited in phase, a circular pattern of constant phase in azimuth results, which radiation serves to provide the carrier signal. The two figure-of-eight patterns are obtained by exciting opposite pairs of the same slots in phase opposition. In this case each pair of slots produces a null normal to the plane of the slots and thereby two figure-of-eight patterns are obtained as the pairs are displaced 90° apart.

One of the advantages to be gained in the present invention is that the slots need not be excited through bridges, and further, no special isolation means are required, since complete and entire isolation, such for instance as to eliminate cross talk, is obtained by the method in which the slots are fed.

A further object and result of the present invention is that a compact unitary structure is obtained which can easily be installed on air fields and vehicles because of its compactness, simplicity and easy operation.

A further advantage of the present invention is that the antenna structure has no insulators other than the material used in covering the slots and only three usual type connectors are used for making electrical connections to the antennas.

There are a very great number of other important features in the design of the present structure but most of these, in order to be appreciated fully, require understanding of the structure and the relation of their various parts which will be more fully appreciated and better understood when set forth in connection with an embodiment of the invention as shown in the drawings, in which:

Figure 1 shows a section in two parts in elevation of the invention with the part shown in the right of the figure comprising the bottom part of the antenna and the part shown in the left comprising the top part of the antenna.

Figures 2 and 3 are sections taken substantially on the lines 2—2 and 3—3 of Figure 1, respectively.

Figure 4 is an enlarged section on the line 4—4 of Figure 3.

Figures 5 and 6 are sections respectively on the lines 5—5 and 6—6 of Figure 1.

Figure 7 is an enlarged section on the line 7—7 of Figure 6.

Figure 8 is a diagrammatic view of the electrical connections across the slots of the antenna shown as developed in a flat plane.

Figures 9*a* and 9*b* show electric fields within the antenna for circular and for figure-of-eight feeds of the slots of the antenna.

Figures 10*a* and 10*b* show diagrammatic circuit arrangements corresponding to Figure 3 and Figure 6.

Referring first to Figure 8, the four slots 1, 2, 3 and 4 represent the four vertical slots of the cylindrical antenna structure 5 shown in Figure 1 in a plane development. These slots are arranged parallel to each other, 90° apart about the cylinder. Each of the slots is fed by four coaxial lines 6, 7, 8 and 9, similarly terminated across the four slots. These coaxial lines come together in a junction box 10 which is fed by a single coaxial line 11. The distance from the junction of the four lines to each terminal across the slots should be approximately one-quarter wave length corresponding to the operating frequency or nearly to that value. When this common feed line 11 is excited, all four slots are excited in the same phase and a circular carrier pattern is radiated.

In the present invention this may be called the carrier signal radiation since its prime purpose is to transmit the carrier signal in all directions, whereas the direction signal is produced by the figure-of-eight patterns. The feed for the figure-of-eight pattern (referring to Figure 8) is through two coaxial lines 12 and 13, each of which have parallel branch feeders 14 and 15 for the feeder 12, and 16 and 17 for the feeder 13. The feeders 14 and 15 terminate across opposite pairs of slots in such direction as to excite them in phase opposition which is indicated by the plus and minus signs at each side of the slot. The feeders 16 and 17 likewise terminate across the slots 2 and 4 in phase opposition as indicated by the plus and minus signs across those slots. These feeds for the side band signal, so-called, are impressed across the slots at their lower end, while the circular or reference feed is impressed across the slots at their upper ends, although those feeds could be interchanged. Any potential exciting across any one slot at the top end due to the side band excitation is opposed by an equal potential of opposite polarity across the opposite slot, so that no energy can pass into the common feed line 11. A further analysis will show that any potential existing across any one slot at the bottom end due to the carrier or reference excitation is opposed to an equal potential of the same polarity across the opposite slot and no energy can pass down either common feed line of the figure-of-eight feed.

The two side band feeds are isolated from one another also because of the method of feed. Referring again to Figure 8 which shows a development around the cylinder or other continuous body, when slots 1 and 3 are excited with the polarity as shown, the same positive voltages appear on each side of the slot 2 and the same negative voltages on each side of the slot 4. Therefore no voltage is induced across the slots 2 and 4 because of the feed

to slots 1 and 3; and similarly no voltage is induced in slots 1 and 3 because of the feed to slots 2 and 4.

The lines leading to the two opposing slots in the figure-of-eight feed should be approximately one-quarter wave length long so that the impedance they present to the carrier or reference signal will be high and hence the disturbing effect on the carrier compensation is minor.

Referring further to the arrangement of Figure 8, it will be noted that all of the coaxial conductors are connected to the slot by connecting the outer conductor to one side of the slot and having the inner conductor bridged across the slot. Because the slot is narrow in terms of wave length, substantially not greater than .03λ with smaller values of 0.01λ and 0.02λ commonly used, vertical polarized radiation caused by the vertical currents will substantially cancel while horizontally polarized radiation will result from the space energy guided by the slots.

In the case of the circular feed, it will be noted that the radiation across the slots as a result of the four feeders 6, 7, 8, and 9, are always in the same rotational direction so that the radiation pattern will be substantially circular and of the same general intensity in all directions. In the case of the excitation by the coaxial cables 12 and 13, for the figure-of-eight feed, it will be noted that the current across the slots 1 and 3 are in opposite directions because of the manner in which the voltages are impressed by the branch conductors 14 and 15. Similarly the branch conductors 16 and 17 impress opposite voltages across the slots 2 and 4. For each of these pairs, 1—3 and 2—4, there will be a null in the radiation pattern perpendicular to the plane of the slots and the general pattern will be two figure-of-eight patterns at right angles to each other.

Each type of excitation, namely for the circular feed and that for the figure-of-eight feed sets up a different kind of field within the cylindrical antenna. For the circular field in which the excitation is in the same rotary direction around the cylinder, a field is set up as shown in Figure 9*a*, from which it will be noted that the effective cavity area is cut in quarters and the effective diameter of the cavity is halved. For the figure-of-eight feed, a field is set up as shown in Figure 9*b* in which the cavity area is not changed. It follows therefore that if the cavity is designed to operate fairly close to cut off for the figure-of-eight feed, it will be too small for the circular feed and the virtual wave length of the slot will be too long, with the result that this current will not vary sinusoidally but will decay exponentially, and further unless the slot is fed in the center, current across the top and bottom will not be equal.

It is known that in an antenna of one slot the operating diameter of the cylinder should be approximately .15 wave lengths so that when a cylinder is designed with the wave length approximately .15 it will be too small to operate efficiently with a circular feed which disadvantage is overcome in the present system by the use of capacity loading in the form of inwardly extending fins on both sides of the slots as indicated by 18 and 19 in Figure 1, which are the fins for slot Nos. 2 and 20, which is one of the fins for slot Nos. 1, and 21, which is one of the fins for slot No. 3. The magnitude of this loading is to give an effective cavity diameter of approximately .15λ.

A further feature of design of the present invention is that the slots which include the windows at each end are made substantially one-half wave length long referring to a virtual half wave length in order that the slot impedance may be substantially real.

With an effective cavity diameter of .15λ the slot length for the circular feed is made substantially one-half wave length. However since the cavity for the figure-of-eight feed is twice the diameter and operates further above cut off than does the circular feed, the virtual wave length of the slot for the figure-of-eight feed is too long by about 20%. This difference in virtual slot length for the two foods is overcome by placing a reactance across the slots in such a manner that the slot is shortened for the figure-of-eight feed but untouched for the circular feed.

Figure 10*a* which corresponds diagrammatically to the arrangement indicated in Figure 3 for the top connection and Figure 6 for the bottom connection, show the voltages on the slots and the loading of the fins for the figure-of-eight feed. If a jumper 22 is connected between the points 1′ and 5′ and another 23 between the points 2′ and 6′, an inductance is placed across the slots 1 and 3 at the point of connection of the jumper and thereby the slots are effectively shortened. Additional jumpers 24, between the points 3′ and 7′ and 25, between the points 4′ and 8′ are effectively for the opposite pairs of slots 2 and 4. Jumpers 22 and 23 may be connected together at their mid-point 30 and so also jumpers 24 and 25 at their mid-point 31, since zero voltage exists at each mid-point with respect to its connecting jumpers. However as regards the circular feed, voltages of which are shown in Figure 10*b*, it will be seen that the points of equal polarity have been connected together. Since in this case the voltages at 1′, 3′, 5′, and 7′ are all positive, and at 2′, 4′, 6′, 8′ are all negative, therefore no reactance has been connected across the slot and the slot length remains unchanged. The reactance which has just been mentioned is adjusted to effectively shorten the slots to make them approximately a virtual one-half wave length for the figure-of-eight feed. The actual construction accomplishing this result will be explained later in connection with the descriptions of Figures 3, 4, 6 and 7.

To broadband the antenna, the point on the fins to which the jumpers are connected near one end of the slots or near both ends of the slots are made adjustably along the slots and the adjustment at one end as shown in the embodiment particularly in connection with Figure 1 is calibrated for frequency. This adjustment is effective principally for the figure-of-eight feed. For circular feed broadband adjustment a calibrated variable capacity 32 is connected across the mid-point of the two sides of jumpers, see the capacity shown in Figure 10*a*, and as employed in Figure 7. This capacity is at zero potential point for the figure-of-eight feed and thus ineffective but is directly connected across the slots for the circular feed with a full potential difference and can be used to adjust the slot lengths for various frequencies.

The impedance of the slots for the circular feed is close to 200 ohms and therefore each slot is fed by a 200 ohm line, namely the lines 6, 7, 8 and 9 which at their junction point are fed by a standard 50 ohm cable 11. Therefore little or no compensation is required for this feed. Since the lines are all connected in parallel, the main feeder will have one-quarter the impedance of each of the four branch feeders. With such an arrangement, I have determined for instance, that for a frequency band between 108 and 118 megacycles, the standing wave ratio without returning does not exceed 2 to 1. In the case of the figure-of-eight feed, the slot impedance may be over 1000 ohms and therefore in order that an efficient transfer of power is effected, proper compensation means should be used. Accurate compensation between two elements, namely, the slot and the feed line should be provided so as to bring the standing wave ratio down to as nearly unity as possible. There are a number of methods by which such compensation may be effected. A method shown in the present application is indicated in Figure 1, where sections 34 and 35 of coaxial lines are connected to the branch feeds 12 and 13 of figure-of-eight feed. The inner conductors of these sections as indicated in Figure 8 extend part way down into the outer conductor but are not connected at their ends to the outer conductor. These inner conducting elements 34′ and 35′ may be adjusted in length to attain the desired low impedance for capacity matching of the feeds to the slots for the figure-of-eight feed.

A further method of matching is to use a series inductance as shown by the sections 36 connected to each

of the slots 1–4 inclusive opposite the termination of the branch feeders 14, 15, 16 and 17. These sections 36 have their inner conductors 36' tied to the end of the outer conducting section and provide about 60° of compensation at the operating frequency. Either or both of these methods of compensation may be used, and in fact the series inductance may set up a fixed value while the capacity impedance may be variably adjusted for making the necessary fine adjustment to obtain a standing wave ratio of unity.

At each end of the slots 1, 2, 3 and 4, are window openings 37 and 38 respectively. These window openings should not be substantially greater than ⅛ of the circumference of the cylinder and are principally used for the purpose of changing the impedance along the slot so that a shorter slot will suffice for general operation.

Referring now more specifically to Figures 1–7 of the drawings, the antenna structure with its various compensating and adjusting means will be more specifically described. The antenna comprises a cylindrical shell 40 which is provided with four slots which already have been designated as 1, 2, 3, and 4. These slots are parallel to one another and to the axis of the cylinder and terminate at their ends in enlarged window openings designated 38 at the top of the structure and 37 at the bottom of the structure. The slots include in their length the window openings so that the virtual half wave length established for the slot length extends from the top of one window opening to the corresponding bottom of the same window opening. The window openings may vary considerably in width and length, the principal purpose being to shorten the total length of the slot by introducing a change of impedance along the slot, the impedance increasing from the smaller slot width to the larger slot width at the window openings. The maximum width of the window openings are, for a cylinder having four slots, not greater than ⅛ of the circumference of the cylinder. It may range from this width down to a width not much more than the slot width, but preferably this should be at least double the slot width. The length of the window opening may also vary substantially. A window whose length is one-quarter that of the overall slot will provide the shortest slot for a virtual half wave length.

As indicated in Figures 2, 3, 5 and 6, each slot is covered with a non-conductive cover 41, which may be of any suitable plastic such as "Teflon" polystyrene or any other plastic material which may have a dielectric constant of one or more which will be taken into account in computing the capacity of the slot.

The chief purpose of covering the slot as well as covering the top and bottom of the structure by cover plates 42 and 43 respectively is to prevent rain and moisture from getting into the unit. The slots and windows are spaced 90° apart.

Each of the slots is similarly loaded as has been previously mentioned by fins 20 and 20' extending inwardly from the slot 1, fins 18 and 19 extending inwardly from the slot 2. Fins 21 and 21' extend inwardly from the slot 3 and fins 44 and 45 extend inwardly from the slot 4. These fins are parallel to each other on each side of the slot and form in general a figure having a double channel section spaced back to back providing flanges lying against the inside of the cylinder on either side of the slot as shown at 46 and 47 through which the fins are riveted to the cylinder. In fact the rivets 48 and 49 may be used to hold in place the slot covers 41 over the fronts of the slots as well as the fins extending inwardly of the slot. Each of the slots on its inside is provided with an insulating plate 50 which lie against the inner flanges 51 and 52 of the fins, these numerals being applied only to the fins 18 and 19 but the same structure is used for each of the four fins. The insulating plate is held to the fins by a series of rivets 53, see the right portion of Figure 1.

At the top of each fin there is supported by bolts or rivets 54, angle brackets or arms, 55, 56, 57, 58, 59, 60, 61 and 62. The horizontal arm of the angle brackets 56, 58, 60 and 62 are connected to a conductive plate 63 while the horizontal arms of the brackets 55, 57, 59 and 61 are connected to the conductive plate 64. These plates are one above the other. The connection diagrammatically represented in Figure 10*a* is accomplished in this manner. The plates 63 and 64 which are indicated as vertically above each other in Figure 4, are tied together by an insulating plate 65 which is half way between two plates 63 and 64 and which is supported to each of the brackets as shown in Figure 4.

It will be noted that the plates 63 and 64 are connected to the brackets through right angle arm pieces each of which have a face in contact with the insulating plate 65; the arms 66 of the plate 65 lying on top of the insulating plate 65 and the arms 67 of the plate 64 lying on the bottom of the insulating plate 65. All of the connecting brackets to the fins and the insulating plate are therefore tied together as a unitary structure.

A rough adjustment is provided for the position of this connection by the bolt or rivet holes 54. (See Figure 4.) The top bolt hole may be used with only one rivet, in which case the whole unit as indicated in Figure 4 may be raised the distance between the bolt holes. When the antenna is set up for use, this adjustment may be made as a permanent adjustment if desired.

The circular feed for the antenna is by means of the cable 11 (see Figures 1 and 8), one side of which may be grounded by the ground plate 68 which will be the outside conductor. The inside conductor is provided with four branch extensions, two of which, 69 and 70, shown in Figure 1, extend to corresponding sides of the slots 1 and 2 and are connected at these points. All of the single wire branch conductors are spaced from the center walls of the cylinder by insulators 71 at such a distance to provide the correct line impedance for the connections to the slots. As has been previously stated, where the cable 11 is a 50 ohm cable, the impedance established and the single wire connections should be 200 ohms.

Figure 2 shows the four single wire connections for the circular feeds for slots 1, 2, 3 and 4, the single wire for 3 and 4 being 69' and 70' respectively. The single wire cable 11 is shown also in the group of cables in the right of Figure 1. The other two cables 12 and 13, for the figure-of-eight feed are also in this group. The two wires 12 and 13 as indicated in Figure 1, extend upwards within the cylinder from the bottom. The coaxial cable 12 has two upwardly extending branches 14 and 15, the branch 14 being shown in the right portion of Figure 1 and the branch 15 being shown in section where it extends to the opposite slot. The coaxial cable 13 has its two branches clearly shown in Figure 1 as 16 and 17. These branches 16 and 17 have their outer terminals connected to one side of the slot at the junctions 73 and 74 for the outer conductors of 16 and 17 respectively, and the inner conductors bridging across the slot and are connected at the opposite sides of the slot. This is seen by the connections 75 and 76 respectively, in Figure 6. The same structural arrangements for the connecting of the coaxial cable 16 and 17 to the slots 1–3 is also used for the slots 2 and 4. The jumper arrangement indicated in Figure 10*a* is also used at the lower end of the slots in the cylindrical structure. This is shown in plan in Figure 6 and in elevation in Figure 7. A central insulating plate 80 (see Figures 6 and 7) in the form of a square with four side extensions 81, 82, 83 and 84, has attached to it conductor angle brackets 85, 86, 87 and 88, which have upwardly extending arms attached to conductive plates as for instance 89, see Figure 7, which in turn are fastened to the inward flanges of the slots by means of screws 90.

There are also four such upwardly extending brackets, 91, 92, 93 and 94, which are attached to a similar set of plates 95 as the plate 89. All of the plates 89 and 95 are slotted as indicated by 97 and 98 and the arms are adjustably attached by means of nuts and bolts 96

which have enlarged heads with shanks passing through the slots. These slots in the plates **89** and **95** are seen in the upper right hand part of Figure 1. By means of this adjustment, the whole of the assembly of jumpers at the lower end of the slot may be moved up and down for the length of the slots **97** and **98** in the plates **89** and **95**.

As has been previously explained in connection with Figure 3, for the upper jumpers, the actual connection of the various fins together are effected by two parallel plates **99**, beneath the plate **80**, and **100** above the plate **80** for completing the jumper connections at the lower part of the slots. The plate **99** is tied electrically to the angle brackets **91**, **92**, **93** and **94**, which connects to the other four sets of fins, each plate having a connection to one of the fins of each slot, the connection being arranged as diagrammatically indicated in Figure 8.

The plates **99** and **100** have a central bore or opening aligned with each other and also the plate **80** has a bore aligned with the bores or holes in the plates **99** and **100**. See Figure 7. Surrounding the hole in the plate **99** is a split collar **101**, which may be attached to the plate **99** by suitable means as for instance the nut and bolt **102**.

Working within the split collar is one part of a capacitive unit **32**, which may be rounded in shape if desired and extend upwards into the other half of the unit comprising a cylinder **104**, which is lined with a dielectric sleeve and guide **104'**.

A collar **105** is mounted by means of a bolt and nut **106** on the top plate **100** and this holds in place the cylinder **104** which may be secured in the collar by means of the set screws **107** extending through the side of the collar. The core **103** forming the movable part of the condenser **32** which may be made of suitable conductive material, is adjusted in place in accordance with its calibrated scale and the split collar **101** is then tightened in place when the desired adjustment has been obtained. This provides the capacitive adjustment across the two set of jumpers as diagrammatically shown in Figure 10*a* by the condenser **32**.

Each slot, **1**, **2**, **3** and **4**, may also have an adjustable trimming condenser **109** connected across it about the middle of the slot. Such a condenser may be constructed as shown in Figure 1. A fixed plate **110** may be secured to the flange, as for instance **18** on one fin of the slot and an adjustable plate **111** may be secured to the opposing flange **19** on the other fin of the slot. The adjusted plate **111** may be mounted on a threaded shaft **112** which may be screwed in and out of a nut **113** fixed to the flange **19**. A lock nut may be used to lock the plate **111** in place after the desired adjustment has been made. Each of the four slots may be similarly compensated for fine adjustment to make a final balance of the loads on the slots.

The embodiment shows rectangular windows at the ends of the slots but it is also possible to use other shaped windows as for instance, oval, triangular, polygon shape or square with rounded corners providing the same effect of shortening the necessary length of the total slot is accomplished. The length of the windows may also vary greatly although a shorter window is preferable for constructional purposes and further the feeds for both the circular pattern and the figure-of-eight pattern should be connected to the slots in their narrow sections in from the end windows.

Having now described my invention, I claim:

1. An electromagnetic wave radiator comprising a conductive shell having a longitudinal axis with a plurality of slots parallel to said axis in the surface of the shell, means for feeding said slots with high frequency electric waves comprising a feeder to supply potentials in the same phase to each slot and feeders to supply opposing phases to pairs of slots, and means connected near the ends of the slots for effectively shortening the lengths of the slots for the feeders to the pairs in phase opposition without affecting the effective length of the slot for the feeder supplying the slots in the same phase.

2. An electromagnetic wave radiator comprising a conductive shell having a longitudinal axis with a plurality of slots parallel to said axis in the surface of the shell, means for feeding said slots with high frequency electric waves comprising a feeder to supply potentials in the same phase to each slot and feeders to supply opposing phases to pairs of slots, and means for connecting a reactance across the slots to decrease the slot lengths for the feeders in phase opposition without affecting the length for the feed in the same phase.

3. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, each of said slots having inwardly extending fins, means for electrically feeding all of the slots near the same corresponding ends in the same phase, means for electrically feeding said slots in pairs at the opposite ends in phase opposition with the phase of the pairs displaced 90° from each other and means for compensating the slots for length for each feed to make each slot length for both types of feed a virtual half wave length corresponding to the radiated wave.

4. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, means for electrically feeding all of the slots near the same corresponding ends in the same phase, means for electrically feeding said slots in pairs at the opposite ends in phase opposition with the phase of the pairs displaced 90° from each other and means for compensating the slots for length for each feed to make each slot length for both types of feed a virtual half wave length corresponding to the radiated wave.

5. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, and electrically closed at each end, means for electrically feeding all the slots near one end in the same phase for a circular field pattern whereby the fields across the slots have the same rotational direction, means for electrically feeding opposite slots at the other end for a figure-of-eight feed in rotational phase opposition with one pair at right angles to the other whereby cross current between adjacent slots is eliminated, reactance means connected diagonally across opposite slots with the neutral points of the reactances connected diagonally across connected together, thereby shortening the effective length of the slots for a figure-of-eight feed without affecting the slot length for a circular feed.

6. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, and electrically closed at each end, means for electrically feeding all the slots near one end in the same phase for a circular field pattern whereby the fields across the slots have the same rotational direction, means for electrically feeding opposite slots at the other end for a figure-of-eight feed in rotational phase opposition with one pair at right angles to the other whereby cross current between adjacent slots is eliminated, reactance means connected diagonally across opposite slots with the neutral points of the reactances connected diagonally across connected together thereby shortening the effective length of the slots for a figure-of-eight feed without affecting the slot length for a circular feed, and a condenser connected across said neutral points.

7. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, and electrically closed at each end, means for electrically feeding all the slots near one end in the same phase for a circular field pattern whereby the fields across the slots have the same rotational direction, means for electrically feeding opposite slots at the other end for a figure-of-eight feed

in rotational phase opposition with one pair at right angles to the other whereby cross current between adjacent slots is eliminated, reactance means connected diagonally across opposite slots with the neutral points of the reactance connected diagonally across connected together, thereby shortening the effective length of the slots for a figure-of-eight feed without affecting the slot length for a circular feed, and means for adjusting the position of said reactance means.

8. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, and electrically closed at each end, means for electrically feeding all the slots near one end in the same phase for a circular field pattern whereby the fields across the slots have the same rotational direction, means for electrically feeding opposite slots at the other end for a figure-of-eight feed in rotational phase opposition with one pair at right angles to the other whereby cross current between adjacent slots is eliminated, reactance means connected diagonally across opposite slots with the neutral points of the reactances connected diagonally across connected together, thereby shortening the effective length of the slots for a figure-of-eight feed without affecting the slot length for a circular feed, and a condenser connected across said neutral points, means for adjusting the position of said reactance means and means for adjusting the magnitude of said condenser.

9. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, means for electrically feeding each slot at one end all in the same phase, for a circular pattern, means for feeding said slots at their other ends in pairs in phase opposition with the phase of the pair 90° displaced from each other for a figure-of-eight pattern, and means for matching said latter feeders with the slots for a figure-of-eight feed.

10. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, means for electrically feeding each slot at one end all in the same phase for a circular pattern, means for feeding said slots at their other ends in pairs in phase opposition with the phase of the pair 90° displaced from each other for a figure-of-eight pattern, and means for matching said latter feeders with the slots for a figure-of-eight feed, including a capacitive matching length of coaxial cable connected to said feeders before the connection with the slots.

11. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in

the surface thereof 90° apart from one another, means for electrically feeding each slot at one end all in the same phase for a circular pattern, means for feeding said slots at their other ends in pairs in phase opposition with the phase of the pair 90° displaced from each other for a figure-of-eight pattern, and means for matching said latter feeders with the slots for a figure-of-eight feed, including series inductance compensation connected at the junction of the feeders and the slots.

12. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, means for electrically feeding each slot at one end all in the same phase for a circular pattern, means for feeding said slots at their other ends in pairs in phase opposition with the phase of the pair 90° displaced from each other for a figure-of-eight pattern, and means for matching said latter feeders with the slots for a figure-of-eight feed, comprising series inductance and capacitive compensation.

13. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, means for electrically feeding each slot at one end all in the same phase, and at their other ends in pairs in phase opposition with the phase of the pairs displaced in phase 90° from each other, whereby both a circular reference pattern and two figure-of-eight patterns of radiation are obtained, and adjustable capacitive means connected across the slots for balancing the load on each slot.

14. An electromagnetic wave radiator comprising a cylindrical conductive shell having longitudinal slots in the surface thereof 90° apart from one another, means for electrically feeding each slot at one end all in the same phase, and at their other ends in pairs in phase opposition with the phase of the pairs displaced in phase 90° from each other, whereby both a circular reference pattern and two figure-of-eight patterns of radiation are obtained, and adjustable capacitive means connected across each slot for balancing the load on each slot.

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