

Sept. 15, 1964

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SLOT RADIATOR IN WALL OF COAXIAL FEED
HAVING MODE COUPLING MEANS AT SLOT

3,149,336

Filed Feb. 17, 1961

3 Sheets-Sheet 1

Fig. 1.

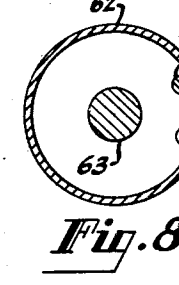
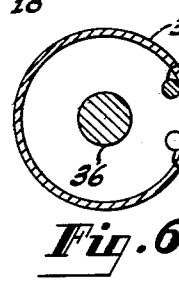
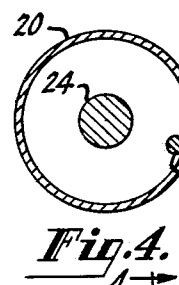
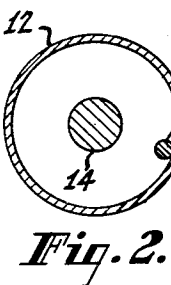
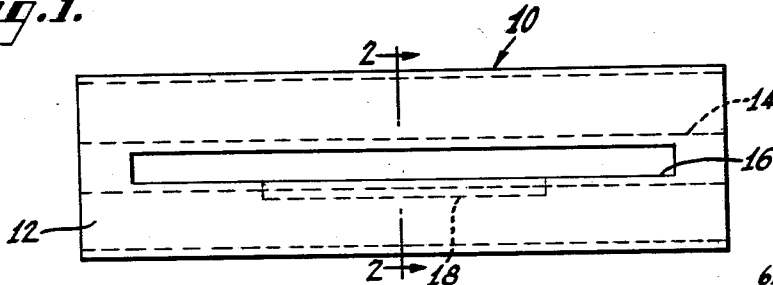


Fig. 2.

Fig. 4.

Fig. 6.

Fig. 8.

Fig. 3.

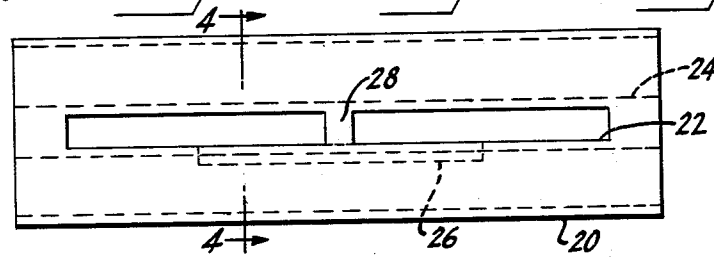


Fig. 5.

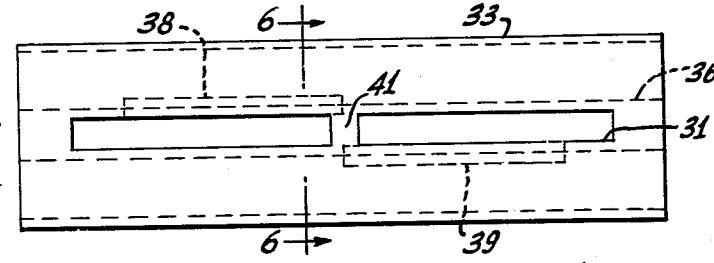
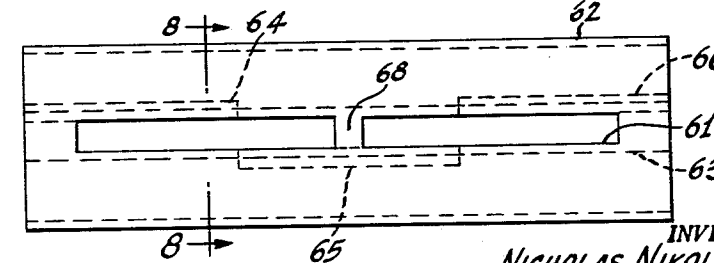


Fig. 7.



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Fig. 9.

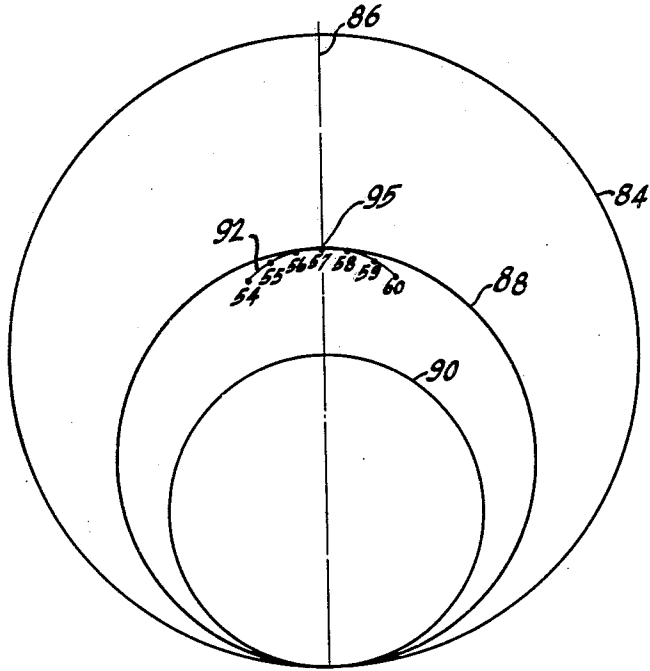
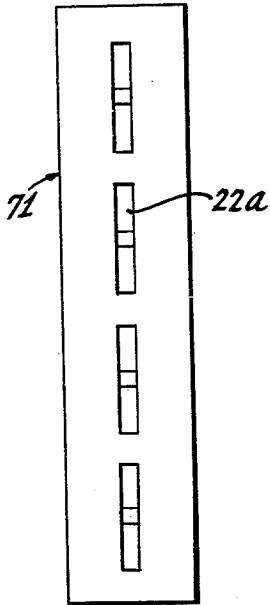


Fig. 13.

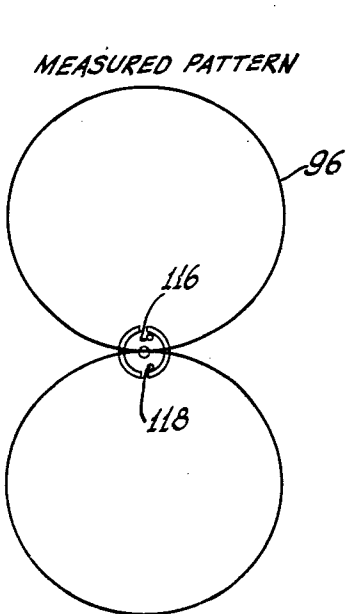


Fig. 14.

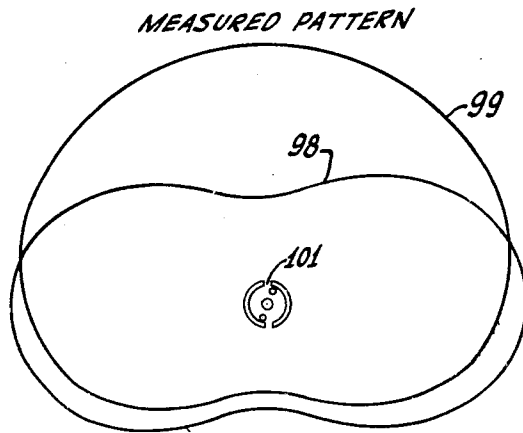


Fig. 15.

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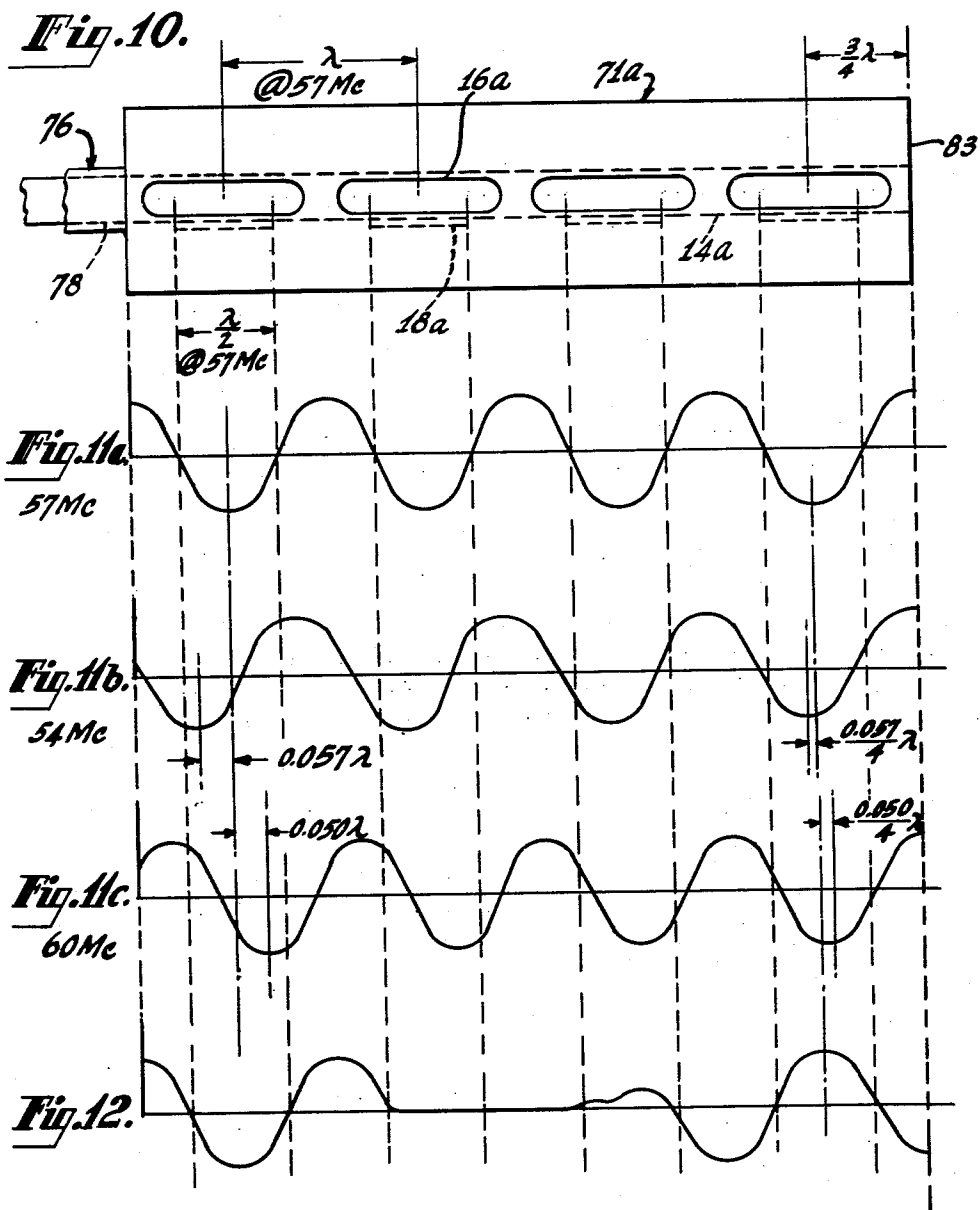
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SLOT RADIATOR IN WALL OF COAXIAL FEED HAVING MODE COUPLING MEANS AT SLOT

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12 Claims. (Cl. 343-771)

The present invention relates to energy radiating slots in a conductive member, and more particularly to a novel combination of one or more coupling devices in combination with a single shorted slot or to an equivalent series of aligned slots wherein the portions of the conductive member separating the aligned slots may be considered effective as a shorting member.

Some types of known radio frequency slot radiators comprise a center feed conductor surrounded by a conductive shell radiator having a plurality of longitudinally disposed radiating slots therein each having a length of about $\frac{3}{4}$ wavelength at the operating frequency. Each radiating slot has disposed closely adjacent to a side thereof a coupling element having a length of about $\frac{1}{2}$ wavelength at said frequency.

In accordance with the instant invention improved power efficiency, improved radiation pattern definition, and other advantages as will appear hereinafter, are provided in this general type of slot radiator by providing more closely longitudinally spaced radiating slots each having lengths of only about $\frac{1}{2}$ wavelength, and longitudinal coupling elements closely disposed adjacent the side edges of said slots wherein said element at least partially overlaps the conductive shell region between the slots. Usually, this conductive member will be in the form of a cylinder, or it may be one of the sides of a tower-like VHF broadcast antenna which is polygonal in horizontal cross section.

An object of the present invention is to provide an improved slot radiator which permits attainment of novel results without the necessity for resorting to excessively long and/or wide slots in a conductive member which would cause mechanical weakening of the conductive member.

Another object of the present invention is to provide a slot in a conductive member capable of greater power radiation than slots known heretofore.

A further object of the present invention is to provide a novel radiating slot which radiates at a phase angle of 180° with respect to slots of known kind.

Still another object of the present invention is to provide a novel radiator slot having a reflected impedance into the supply source for the power to be radiated which is in the neighborhood of one half of that of a more conventional slot.

A still further object of the present invention is to provide a relationship of parts in a radiating conductive member of the type employing standing wave excitation and its associated feed means, so that an input impedance can more readily be obtained that is substantially equal to one half of the characteristic impedance of the radiating conductive member.

Other objects and advantages of the present invention will, of course, become apparent and immediately suggest themselves to those skilled in the art to which the invention is directed from a reading of the following specification in connection with the accompanying drawing in which:

FIG. 1 shows a longitudinal view of a single slotted portion of a coaxial transmission line radiator or antenna utilizing a coupler member of a known kind;

FIG. 2 is a view in sectional elevating of the radiator of FIG. 1, the section being taken on line 2-2 of FIG. 1 as viewed in the direction of the arrows;

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FIG. 3 is a fragmentary showing of the improved slot and coupler arrangement of the present invention as it would be formed in a conductive member, such, for example, as the external cylindrical member of the radiator of FIG. 1;

FIG. 4 is a view in sectional elevation in which the conductive member having the improved slot of FIG. 3 is cylindrical, the section in the slot area being taken along line 4-4 of FIG. 3 as viewed in the direction of the arrows;

FIG. 5 is a fragmentary showing, similar to FIG. 3 of the improved slot and coupler arrangement of this invention in modified form;

FIG. 6 is a view in sectional elevation, similar to FIG. 4, the section in the slot area being taken along line 6-6 of FIG. 5 as viewed in the direction of the arrows;

FIG. 7 is a fragmentary showing, similar to FIG. 3, of the improved slot and coupler of this invention in a further modified form;

FIG. 8 is a view in sectional elevation, similar to FIG. 4, the section in the slot area being taken on line 8-8 of FIG. 7;

FIG. 9 is a view, more or less diagrammatic, of an antenna embodying a plurality of sections, each section being provided with one or more of the improved slot radiators of the present invention;

FIG. 10 is a schematic view of an antenna, composed of a plurality of slotted portions as shown in FIG. 1 and arranged in a horizontal position to cooperate functionally with FIGS. 11a to 11c and FIG. 12;

FIGS. 11a, 11b and 11c show voltage distributor curves for a series of separated excitation frequencies of the antenna of FIG. 10;

FIG. 12 shows a voltage distribution curve aligned with FIGS. 10 to FIGS. 11a, 11b and 11c to illustrate existing conditions when the teaching of an important aspect of the present invention is practiced;

FIG. 13 is a Smith chart plot illustrating the benefit obtained in practicing the present invention with respect to the bandwidth of the input impedance;

FIG. 14 is a plot showing the horizontal radiated pattern of an antenna embodying the present invention; and

FIG. 15 is a plot showing the horizontal radiated pattern of an antenna with and without benefit of the present invention.

In FIG. 1 the slotted coaxial transmission line 10 is a hollow cylindrical outer conductor 12 and a concentric inner conductor 14. The dominant mode for the coaxial transmission line 10 is the TEM mode, and radio frequency energy propagated through the transmission line 10 has a transverse electric field in radial directions. An elongated or rectangularly shaped slot 16 is provided in the outer conductor 12, and is positioned with its longer edges substantially parallel to the longitudinal axis of the transmission line 10. A voltage or radiating field is developed across the slot 16 by a coupler member 18 secured at, or adjacent, one edge of the slot. This coupler member is similar to that shown in the copending application of Steven J. Bazan, Serial No. 685,920, filed September 24, 1957, now Patent No. 2,981,947, granted April 25, 1961.

In accordance with the present invention, as illustrated in FIGS. 3 and 4 of the drawing, a conductive member 20 is provided with a slot 22 and, as will be seen upon reference to FIG. 4 of the drawing, the conductive member 20 may be the outer conductor 12 of a transmission line having a concentric inner conductor 24. The length of the slot 22 will vary in accordance with the desired frequency of the signal which is to be radiated by or from the slot 22. In the showing of FIG. 1 of the known slot and coupler it is usual practice to have a slot length varying from 0.5λ to 0.9λ . λ represents a wavelength

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at the operating frequency. In the arrangement of FIGS. 3 and 4 constructed in accordance with the present invention, the length of the slot 22 is substantially in the neighborhood of one wavelength (λ). However, it will be understood in view of the foregoing statement that it can also vary from 0.5λ to 0.9λ . The coupler member 26, which corresponds in function with the coupler member 18 of FIG. 1 is in the neighborhood of $\lambda/2$.

As pointed out in the foregoing, the improved slot radiator of this invention is short circuited between its ends. In FIGS. 3 and 4 of the drawing a conductive member 28 provides the short circuit. It will be understood that the invention may be carried out by providing two aligned slots separated by an integral portion of the conductive member 20 to, in effect, provide a single short circuited slot having the coupling member 26 associated therewith. The width of the short circuit member 28, which extends longitudinally of the slot 22 is or may be in the neighborhood of 0.1λ . In most instances, the short circuiting member 28 will be less than 0.1λ in width.

For a given coupler member 26, the shorted slot of this invention radiates about 6 db more power than a conventional slot and at a phase angle of 180° with respect to the conventional slot. In connection with FIG. 10 and its associated figures the frequency ranges generally under discussion will appear.

FIGS. 5 and 6 of the drawing illustrate a radiating slot 31 constructed in accordance with the present invention in modified form. The slot 31 is formed in a conductive member 33, which upon reference to FIG. 6 of the drawing may be in the nature of an outer member of a radiating antenna. As pointed out above the circular configuration of the member 33 is shown illustratively, but it will be understood that this member 33 may be of different shapes in cross section and it may comprise an open mesh of electrically conductive material supported suitably by known structural members such as metallic angles, channels or like members of suitable mechanical strength. A concentric inner conducting member 36 is shown in FIG. 6 to cooperate with the conductive member 33 in the event that the latter is of any one of the suggested cross sectional shapes.

Coupler members 38 and 39 are positioned to cooperate with the conductive member 33, the slot 31 and the inner conductor 36. A short circuiting member 41, similar in proportion to the member 28 of FIG. 2 of the drawing is provided. The shorted slot 31 may have the dimensions indicated in the foregoing in terms of a wavelength. The coupler members 38 and 39 are positioned longitudinally of the slot 31 so that their total effective length is in the neighborhood of one wavelength. The slot 31, therefore, is or may be longer, in proportion to the total effective coupler length, than the slot of FIG. 3. The short circuiting member 41 is in the neighborhood of 0.1λ . Usually, it will be less than 0.1λ .

FIGS. 7 and 8 of the drawing illustrate a radiating slot 61 constructed in accordance of the present invention of a still further modified form. Referring to these figures, the slot 61 is formed in a conductive member 62 and upon reference to FIG. 8 of the drawing it will be seen that this conductive member may be similar in cross section, or it may be, as stated above, of any other shape in cross section so as to cooperate with an inner conductor member 63. Coupler members 64, 65 and 66 are provided for cooperation with the slot 61. These three coupler members appear in their relative positions with respect to the slot in FIG. 7. However, in FIG. 8 the coupler member 66 is obstructed from view.

In the arrangement of FIGS. 7 and 8 the coupling members 64, 65 and 66 in conjunction effectively couple to the inner conductor 63 over one and one half wavelength. In the illustrative example this is shown illustratively and the three coupling members are indicated as being of the same length. However, it will be understood that the diameters of the coupling members may be varied to

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change one or more of the parameters affecting the operation of the slot 61 as a radiating slot. This is also true of the coupler members 38 and 39 of FIGS. 5 and 6. A short circuiting member 68, also similar in proportion and function to the member 28 of FIG. 2 of the drawing, is provided.

FIG. 9 of the drawing shows an antenna 71 constructed to include a plurality of shorted slots of the presented invention arranged to provide a vertical antenna array. In the illustrative showing of FIG. 9, four vertical aligned shorted slots 22a are shown, but it will be understood that the number may be greater or less depending upon the desired service coverage and the field strength requirements at various predetermined locations in the service area. The radiation pattern can be predetermined in accordance with the invention to prevent co-channel interference or other kinds of interference with existing television transmitters operating in near-by areas. The antenna of FIG. 9 is or may be fed in the usual manner by a coaxial transmission line (not shown). The slots 22a may be shorted and fed as shown in FIGS. 3, 5 or 7 or in any combination thereof depending upon the horizontal radiated pattern of energy which is desired for a given use of the antenna 71.

FIG. 10 of the drawing shows an antenna 71a constructed of a plurality of transmission line elements, such as are shown in FIG. 1, to provide a vertically stacked array. It will be understood that the manner of arranging these elements is such as to attain a broad band impedance and a desired pattern for UHF and VHF TV broadcasting antennas using standing wave excitation. In the following discussion of the attainment of this result it will be understood that the shorted slot of this invention is preferably employed. However, in the interest of simplicity, the showing of FIG. 10 has been confined to the slots 16 and coupler members 18, which are designated 16a and 18a on FIG. 10, for the sake of simplicity of explanation. The operation of the invention described with reference to FIG. 9 is also applicable to the structure and operation of FIG. 10.

The antenna 71a is or may be fed in the usual manner by a coaxial transmission line 76. It will be understood that the inner conductor 78 proceeds upwardly through the antenna to provide the inner conductive member 14a of the antenna structure when the antenna is considered as a radiator of electrical energy.

In accordance with this phase of the present invention it was discovered that the impedance bandwidth varied with the level of the input impedance. If the input impedance is equal to one half the characteristic impedance of the antenna then the impedance bandwidth is optimized. Consequently, if the antenna illumination depends on the input impedance then the pattern bandwidth is also optimized. Antenna illumination is known in the antenna art to refer to radiation along the antenna. As penetration inwardly and radially of the coupler members increases, the loading presented to the transmission line, considered as an antenna, increases. Penetration is selected for each layer or section of the antenna so that the total loading is equal to one half of the characteristic impedance of the antenna. Adjustment of the coupler penetration and slot lengths, in accordance with this aspect of the invention, is such that for a given illumination the impedance relationship explained above is effected.

FIGS. 11a to 11c indicate voltage distribution on the illustrative example of an antenna in which the spacing designated by λ is one wavelength between the longitudinally spaced centers of the slots 16a. In the illustrative example λ is assumed to be at 57 megacycles and the length of each coupler member 18a is assumed to be $\lambda/2$ at 57 megacycles. The antenna in effect is short circuited at its end 83 and the longitudinal center of the slot 16a nearest this short is assumed to be spaced $3/4\lambda$ from the short.

The voltage curves on the graphs of FIGS. 11a to 11c

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indicate the voltage standing wave distribution in the antenna for 57 mc. input in FIG. 11a; 54 mc. input in FIG. 11b; and 60 mc. input for FIG. 11c. It will be observed that in FIG. 11b the voltage nodal point is displaced 0.057λ from the longitudinal center of the first slot longitudinally of the antenna whereas in FIG. 11c the voltage nodal point is displaced 0.050λ in a different phase direction from the same slot center.

FIG. 13 is a Smith chart having the usual chart outline 84. The line 86 represents the resistive component of the input impedance Z of an antenna, in accordance with the present invention, divided by the characteristic impedance Z_0 of the antenna. Circle 88 is a plot of R/Z_0 , which in this example is 0.5. R is the resistive component of the input impedance Z of the antenna. Circle 90 is a plot of R/Z_0 equal to unity.

Curve 92 is a plot of the input impedance of an antenna when there is no compensation which compensation is taught in the present invention. The point 95 on the chart indicates the nature of the input impedance when compensation is employed in accordance with teachings of the present invention.

When compensation is employed in accordance with the teaching of this phase of the present invention as above stated the voltage distribution curve for 54 mc., 57 mc., 60 mc. and all frequencies in between is indicated by FIG. 12. At some point along the antenna, $Z=Z_0$ and the antenna is, in effect, short circuited at its end 38. Also the input impedance plot reduces to a single point coinciding with and represented by the 57 mc. impedance point 95 as shown by FIG. 13.

FIG. 14 of the drawing shows a measured figure eight radiation pattern 96 with shorted slots and two conductive coupling devices 116 and 118 arranged as shown.

FIG. 15 of the drawing shows a measured cardioid pattern 99 when the slots, associated with the conductive coupling devices are shorted. A peanut shaped pattern 98 results when the slots are not shorted.

What is claimed is:

1. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, a single elongated conductive member fastened to the inner wall of said outer coaxial member at one side of said elongated slot opening with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot, said conductive member having a length of the order of $\lambda/2$, where λ is the RF wavelength, and a member disposed across said slot from side to side thereof whereby to provide a short circuit located intermediate the ends of said slot and intermediate the ends of said elongated conductive member.

2. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, a single elongated conductive member fastened to the inner wall of said outer coaxial member at one side of said elongated slot opening with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot, said conductive member having a length of the order of $\lambda/2$, where λ is the RF wavelength, said slot having a length of 1λ , and a member disposed across said slot whereby to provide a short circuit intermediate the ends of said slot and intermediate the ends of said elongated conductive member.

3. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, a single elongated conductive member fastened to the inner wall of said outer coaxial member at one side of said elongated slot opening with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot, said conductive member having a length of the order of $\lambda/2$, where λ is the RF wavelength, said slot having a length of 1λ , and a member disposed

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across said slot whereby to provide a short circuit intermediate the ends of said slot and intermediate the ends of said elongated conductive member, said member disposed across said slot having a length of $.1\lambda$ in the longitudinal direction of said slot.

4. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, a single elongated conductive member fastened to the inner wall of said outer coaxial member at one side of said elongated slot opening with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot, said conductive member having a length of the order of $\lambda/2$, where λ is the RF wavelength, said slot having a length of 1λ , and a member disposed across said slot whereby to provide a short circuit intermediate the ends of said slot and intermediate the ends of said elongated conductive member, said short circuiting member having a length of less than $.1\lambda$ in the longitudinal direction of said slot.

5. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, said members being capable of presenting a transverse electric field between them in radial directions upon excitation by radio frequency energy, a single elongated conductive member positioned with respect to the inner wall of said outer coaxial member to cooperate with one side of the said elongated slot opening and with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot whereby to create a disturbance in said field so that a radiating field appears across said slot, said conductive member having a length of the order of $\lambda/2$, where λ is the radio frequency wave length, and a second conductive member disposed across said slot whereby to provide a short circuit intermediate the ends of said slot and intermediate the ends of said elongated member, said second conductive member having a width longitudinally of said slot of substantially 0.1λ .

6. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, said members being capable of presenting a transverse electric field between them in radial directions upon excitation by radio frequency energy, a single elongated conductive member positioned with respect to the inner wall of said outer coaxial member to cooperate with one side of the said elongated slot opening and with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot whereby to create a disturbance in said field so that a radiating field appears across said slot, said conductive member having a length of the order of $\lambda/2$, where λ is the radio frequency wave length, and a second conductive member disposed across said slot whereby to provide a short circuit intermediate the ends of said slot and intermediate the ends of said conductive member, said second conductive member having a width longitudinally of said slot of substantially 0.1λ .

7. An antenna for providing radiation of electromagnetic energy of a given wavelength, comprising a hollow conductor having a plurality of elongated slots positioned around the periphery of the hollow conductor and extending substantially longitudinally along said conductor for a distance substantially equal to one wavelength of said given wavelength, a single coupler of conductive material positioned within said hollow conductor adjacent one of the longer edges of each of said slots, each of said couplers cooperating with its respective slot and having its longitudinal axis substantially parallel therewith, and a bridging member short circuiting each of said slots substantially midway of the length of its respective slot and coupler, said bridging member having a width extending longi-

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itudinally of its respective slot which is a fraction of said wavelength substantially equal to 0.1.

8. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, said members being capable of presenting a transverse electric field in radial directions between them upon excitation by radio frequency energy, a pair of elongated conductive members positioned with respect to the inner wall of said outer coaxial member to cooperate, one with each side of the said elongated slot opening, each of said members' long dimension being substantially parallel to and substantially registered with said one side of said elongated slot whereby to create a disturbance in said field so that a radiating field appears across said slot, said elongated conductive members being spaced along said slot so that each of said elongated members has an end substantially at the center of said slot longitudinally of said slot and a short circuiting member for said slot adjacent said ends of said elongated conductive members which are substantially at the center of said slot.

9. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, said members being capable of presenting between them a transverse electric field in radial directions upon excitation by radio frequency energy, a conductive member disposed across said slot whereby to provide a short circuit between the ends of said slot, a pair of elongated conductive members positioned with respect to the inner wall of said outer coaxial member to cooperate, one with each side of the said elongated slot opening, each of said conductive members' long dimension being substantially parallel to and substantially registered with its respective side of said elongated slot whereby to create a disturbance in said field so that a radiating field appears across said slot, said elongated conductive members being spaced along said slot so that each of said elongated members has an end substantially at the center of said slot longitudinally of said slot, and said last named ends of said elongated conductive members overlapping said conductive member disposed across said slot.

10. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, said members being capable of presenting a transverse electric field in radial directions between them upon excitation by radio frequency energy, a conductive member disposed across said slot whereby to provide a short circuit between the ends of said slot, a pair of spaced elongated conductive members positioned

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with respect to the inner wall of said outer coaxial member to cooperate with one side of the said elongated slot opening, each of said elongated members' long dimension being substantially parallel to and substantially registered with said one side of said elongated slot whereby to create a disturbance in said field so that a radiating field appears across said slot, a third elongated conductive member positioned with respect to the inner wall of said coaxial member to cooperate with the side of said elongated slot opening opposite said pair of spaced elongated conductive members, said conductive member disposed across said slot being located substantially centrally lengthwise of said slot, and said third elongated conductive member having its longitudinal center substantially aligned transversely with the center of said conductive member disposed across said slot, said pair of elongated conductive members being spaced along said slot so that each member has an end substantially at the center of said slot longitudinally of said slot.

11. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, an elongated conductive member fastened to the inner wall of said outer coaxial member at one side of said elongated slot opening with one side of said member's long dimension substantially parallel to and substantially registered with said one side of said elongated slot, a member disposed across said slot whereby to provide a short circuit intermediate the ends of said slot, and said elongated conductive member having at least a portion thereof overlapping said short circuiting member.

12. Means for radiating electromagnetic energy comprising two coaxial members, said outer member having an elongated slot opening, a plurality of elongated conductive members fastened to the inner wall of said outer coaxial member at one side of said elongated slot opening with one side of the long dimension of each of said members substantially parallel to and substantially registered with said one side of said elongated slot, a member disposed across said slot whereby to provide a short circuit intermediate the ends of said slot, and said elongated conductive members each having at least a portion thereof overlapping said short circuiting member.

References Cited in the file of this patent

UNITED STATES PATENTS

2,574,433	Clapp	Nov. 6, 1951
2,948,895	Ghose et al.	Aug. 9, 1960
2,981,947	Bazan	Apr. 25, 1961