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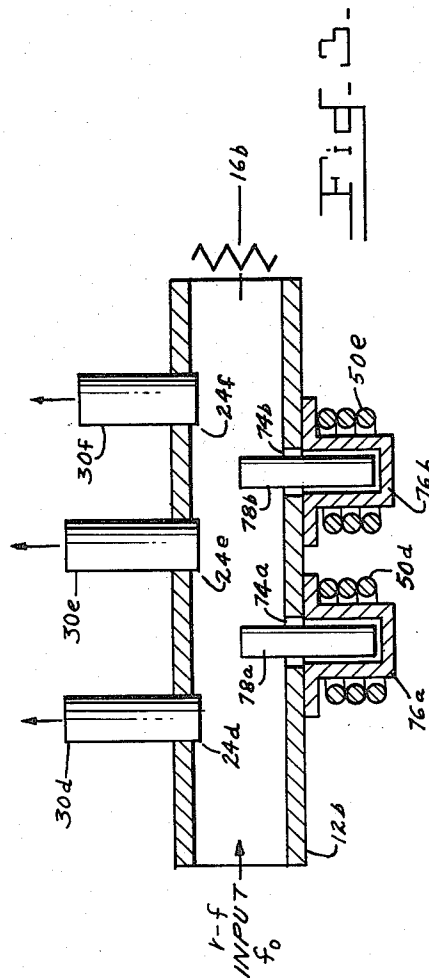
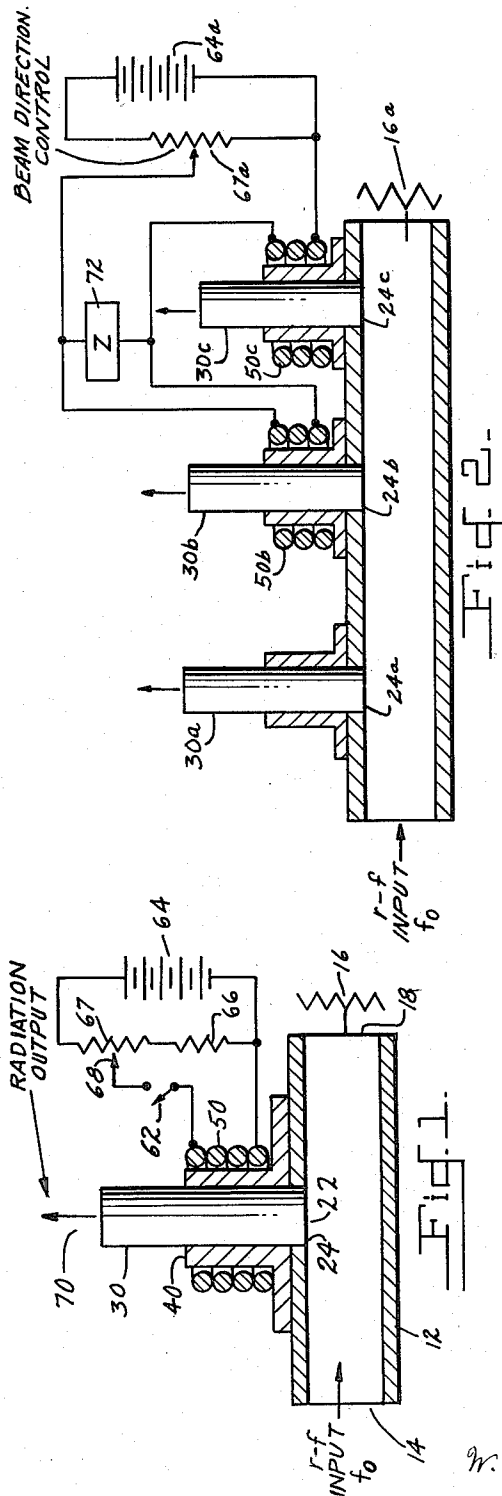
E. G. SPENCER ET AL

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MICROWAVE ENERGY RADIATORS

Filed Dec. 11, 1956

3 Sheets-Sheet 1



INVENTORS,
Edward G. Spencer
Robert D. Hatcher
BY Frank Reggia

W. E. Thibodeau, A. W. Dear & J. P. Elgerton
Attorneys.

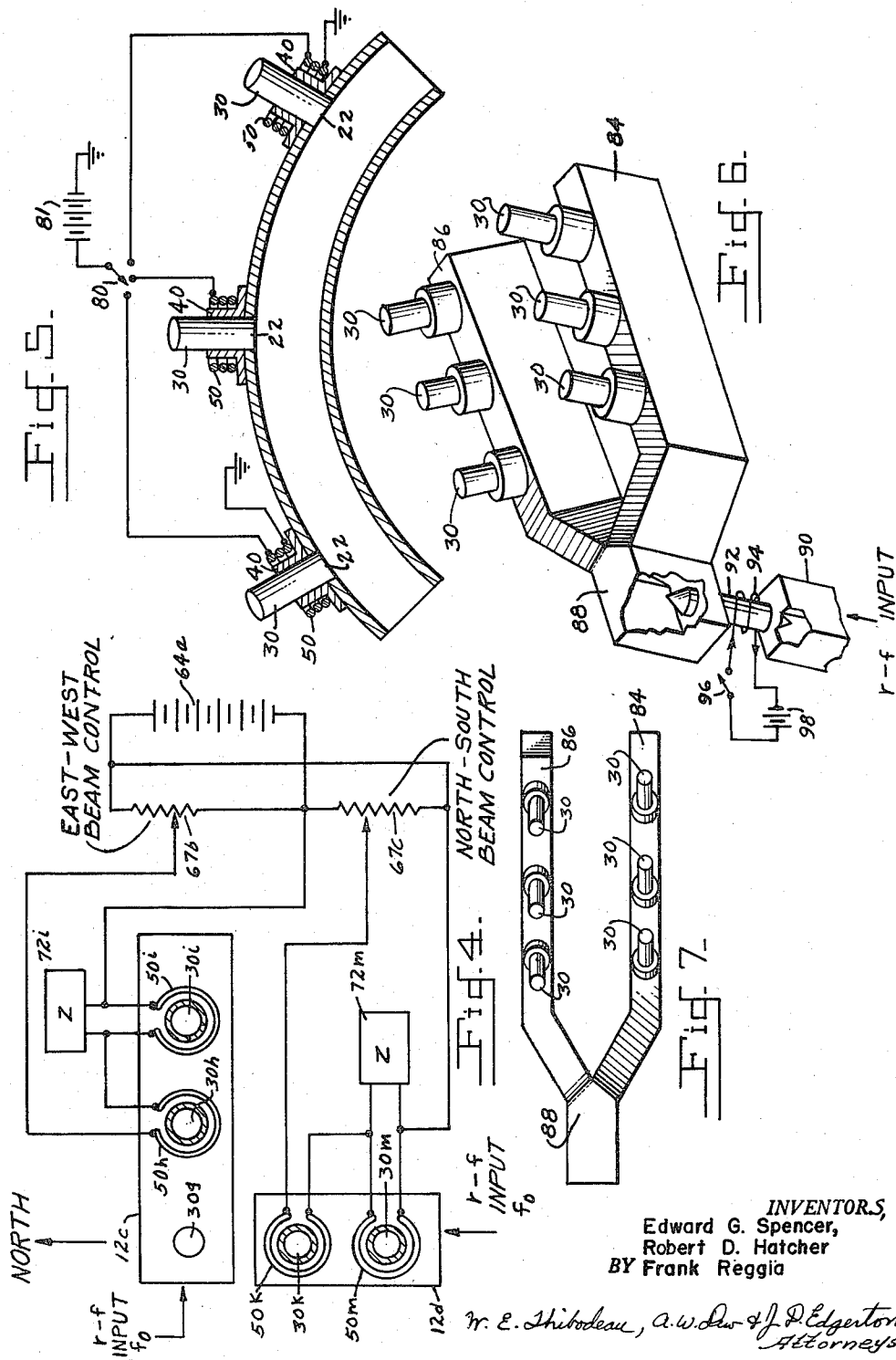
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INVENTORS,
Edward G. Spencer,
Robert D. Hatcher
BY Frank Reggia

W. E. Thibodeau, a.w.d. & J. D. Edgerton
Attorneys.

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3 Sheets-Sheet 3

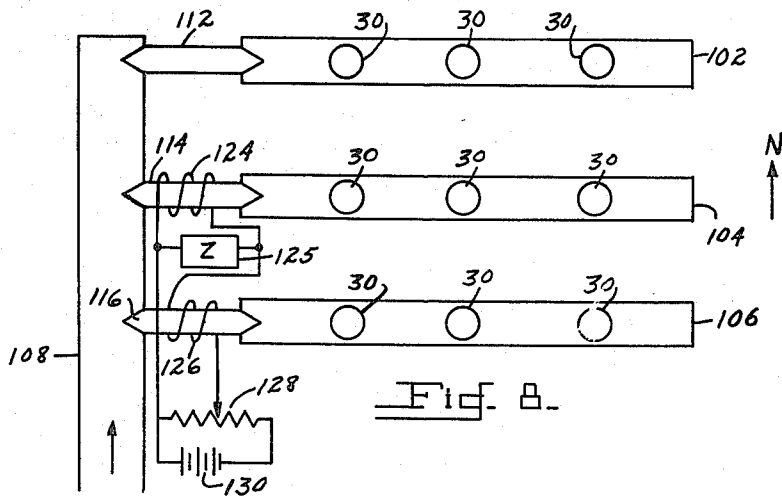


Fig. 8.

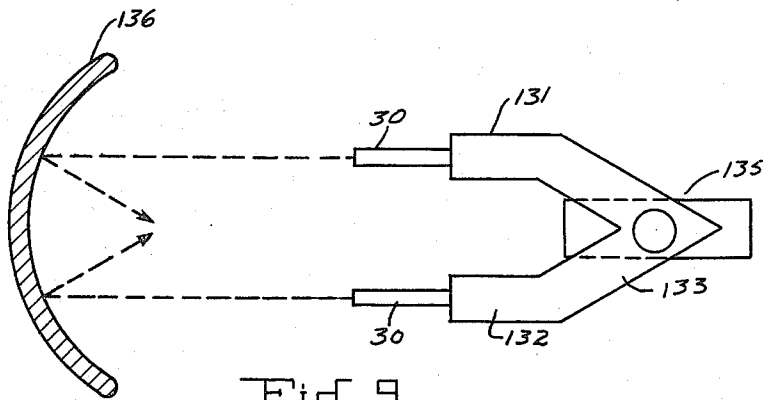


Fig. 9.

INVENTOR.
Edward G. Spencer
Robert D. Hatcher
BY Frank Reggia

W. E. Thibodeau, A. W. Dew & J. D. Edgerton
Attorneys.

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MICROWAVE ENERGY RADIATORS

Edward G. Spencer, Rockville, Md., Robert D. Hatcher, Washington, D.C., and Frank Reggia, Chevy Chase, Md., assignors to the United States of America as represented by the Secretary of the Army

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4 Claims. (Cl. 343—768)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to us of any royalty thereon.

This invention relates to the radiation of microwave energy. The invention provides various energy-radiating devices and arrays in which the active radiating elements are ferrite rods (ferrods) and in which the plane of polarization, mode pattern, phase, or amplitude of the radiated energy is varied by means of a variable magnetic field. Directional arrays are provided in which the radiation pattern of the array may be very rapidly changed—i.e., rapid scanning may be accomplished—by varying the relative phase of the energy radiated by the various elements.

An object of the invention is to provide improved microwave radiators.

Another object is to provide microwave radiating elements wherein the plane of polarization, mode pattern, phase, or amplitude of the radiated energy may be rapidly and conveniently controlled.

A further object is to provide highly compact directional antenna arrays for use at microwave frequencies.

A still further object is to provide improved microwave arrays wherein the radiation pattern may be rapidly and conveniently altered.

Yet another object is to provide methods and devices for microwave beam scanning, in a variety of scanning patterns, without the use of mechanically moving elements.

An additional object is to provide simple, practical, economical, and dependable methods and devices for the accomplishment of the foregoing objects.

Other objects, aspects, uses and advantages of the invention will become apparent from the following description and the accompanying drawings, in which:

Figure 1 is a simplified sectional and schematic representation of a single ferrite rod radiator and associated control means in accordance with the invention.

Figure 2 is a simplified sectional and schematic representation of a plurality of ferrite rod radiators and associated means for controlling the relative phases of the individual signals radiated therefrom, in accordance with the invention.

Figure 3 is a similar representation of an embodiment similar to that shown in Figure 2 except that alternative phase-control means is used.

Figure 4 is a simplified plan view and schematic representation of an antenna array in accordance with the invention in which the individual radiating elements are pointed vertically skyward.

Figure 5 is a simplified sectional and schematic representation of a plurality of ferrite rod radiators and means for selectively energizing the various radiators in accordance with the invention.

Figure 6 is a simplified perspective view and schematic representation of a form of the invention in which micro-

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wave energy may be rapidly switched between two antenna subarrays.

Figure 7 is a simplified top view of the Figure 6 arrangement.

Figure 8 is a simplified top view and schematic representation of a form of the invention in which the phase of the energy applied to certain antenna subarrays may be varied relative to the phase of the energy applied to other subarrays, thereby varying the total radiation pattern.

Figure 9 is a simplified sectional and schematic representation of a form of the invention in which microwave beams emitted from ferrite rod radiators are reflected from a reflecting surface.

In Figure 1, a section of waveguide 12 is adapted to be supplied with microwave energy of frequency f_0 at one end 14 and is terminated in an impedance 16 at the other end 18 in accordance with well-known practice. Microwave energy is coupled from waveguide 12 through a coupling aperture 24 to end 22 of a ferrite rod 30. A metal tube 40 surrounds rod 30 for a portion of its length. A coil 50 is wound around tube 40. Upon the closing of a switch 62 an electric current is applied to coil 50. This current originates in a battery 64 and is of an amplitude related to the value of a fixed resistor 66 and a resistor 67 having an adjustable tap 68 that are connected in series across battery 64.

Tube 40 acts as a section of waveguide. The diameter of rod 30 and the inner diameter of tube 40 are selected to provide a cut-off frequency slightly higher than the microwave frequency f_0 when switch 62 is open. Under these conditions very little energy flows from input end 22 to output end 70 of rod 30. Upon the closing of switch 62, however, current flows through coil 50 and subjects a portion of ferrite rod 30 inside tube 40 to a magnetic field. This magnetic field increases the effective tensor permeability of the ferrite, lowers the cut-off frequency of tube 40 to below the microwave frequency f_0 , and permits energy to flow to end 70 whence it is radiated.

When modulating currents of low frequency are applied to coil 50, tube 40 does not have a substantial shielding effect on the magnetic field produced by the coil. At high modulating frequencies, however, it may be desirable to provide tube 40 with slots, or—better still, in general—to make tube 40 extremely thin, as by letting tube 40 consist of a thin layer of silver paint applied to rod 30.

The values of resistors 66 and 67 are such that tube 40 passes microwave energy even when tap 68 is moved to the low end of resistor 67.

With switch 62 closed, adjustment of the position of tap 68 will (1) rotate the plane of polarization of the energy passing through rod 30, and (2) alter the effective inner diameter of tube 40 in terms of wavelengths at the microwave frequency f_0 . It will be understood that this latter effect may, under some conditions, change the mode pattern of the energy propagated through rod 30.

Of particular present importance, the magnetic field produced by the current flowing through coil 50 introduces a phase delay in the microwave energy flowing through rod 30; the phase of the microwave energy at output end 70 with respect to that at input end 22 can be varied by varying the position of tap 68.

In Figure 2, ferrite rods 30a, 30b, and 30c are coupled to linearly equi-spaced apertures 24a, 24b, and 24c respectively in a section of waveguide 12a that is supplied with microwave energy and terminated in an impedance 16a. Identical coils 50b and 50c surround portions of rods 30b and 30c respectively. Coils 50b and 50c are connected in series to an adjustable voltage source consisting of a beam-angle-control potentiometer 67a shunted across a

battery 64a. Coil 50b is shunted by an impedance 72 of equal value, so that the current through coil 50c is twice the current through coil 50b regardless of the setting of potentiometer 67a.

It will be understood that rods 30a, 30b, and 30c constitute a multi-element antenna array having a major lobe of radiation at an angle dependent upon the phase relation between the energy at the output ends of the three rods. It will be understood also, from what has been said above, that the angle of the major lobe of the array can be controlled by means of potentiometer 67a.

Figure 3 shows another form of variable-angle antenna array. In Figure 3, ferrite rod radiators 30d, 30e, and 30f are coupled to linearly equi-spaced apertures 24d, 24e, and 24f respectively in a section of waveguide 12b that is supplied with microwave energy and terminated in an impedance 16b. Apertures 74a and 74b are provided in another wall of waveguide 12b. With respect to waveguide 12b, aperture 74a is longitudinally midway between apertures 24d and 24e, and aperture 74b is midway between apertures 24e and 24f. Metal cups 76a and 76b are positioned on the outside of waveguide 12b over apertures 74a and 74b respectively. Coils 50d and 50e surround cups 76a and 76b respectively. Ferrite rods 78a and 78b extend from the interior of waveguide 12b through apertures 74a and 74b respectively into the interiors of cups 76a and 76b respectively.

In the arrangement shown in Figure 3, the phase of the energy reaching the input ends of rods 30e and 30f, and thus the phase difference between the energy radiated from rods 30d, 30e, and 30f respectively, and thus the direction of radiation from the array comprising these three rods, can be controlled by the application of suitable currents to coils 50d and 50e.

In the arrays shown in Figures 2 and 3 it will be understood that the radiated beam is of fan-shaped, rather than conical, form. The beam angle is relatively wide (typically of the order of 30 degrees) in a plane perpendicular to the plane of the radiating rods 30 but substantially narrower in the plane of the rods. The axis of the beam is always in the plane of rods 30, but the angle that the axis of the beam makes with the axis of waveguide 12 can be varied.

Figure 4 shows an arrangement for producing a narrow generally conical beam of variable direction. The beam obtained is the resultant of two flattened beams, their broad dimensions at right angles to each other, generated in accordance with the principles disclosed in connection with Figure 2.

In Figure 4 the axes of waveguide sections 12c and 12d are oriented east-west and north-south respectively. Each section is supplied with microwave energy. Ferrite rod radiators 30g, 30h, and 30i extend vertically skyward from waveguide 12c, and ferrite rod radiators 30k and 30m extend similarly from waveguide 12d. Identical coils 50h, 50i, 50k, and 50m surround rods 30h, 30i, 30k, and 30m, respectively. Coils 50i and 50m are shunted by impedances 72i and 72m respectively, the impedances being identical to the coils. An east-west beam control potentiometer 67b permits application of an adjustable direct current to coils 50h and 50i, while a north-south beam control potentiometer 67c similarly permits application of an adjustable direct current to coils 50k and 50m. From what has been said it will be understood that the direction of the resultant beam of the array shown in Figure 4 will be responsive to the settings of controls 67b and 67c. Skilled persons will be able to provide various equivalents of controls 67b and 67c that will permit the beam of the array to be shifted in accordance with any desired periodic or aperiodic program and at very high rates of speed. For example, if sawtooth scanning signals 90 degrees out of phase are substituted for controls 67b and 67c, circular scan will be accomplished. Spiral scan can be provided by amplitude-modulating such sawtooth scanning signals with a sinusoidal or other waves.

Figure 5 shows another way of obtaining beam lobing in accordance with the invention. In Figure 5 a plurality of radiators 30 are surrounded by tubes 40 and coils 50, as in previously described embodiments. Means are provided for supplying microwave energy to ends 22 or rods 30. In accordance with the discussion of Figure 1, the diameter of rods 30 and tubes 40 is so selected, in relation to the microwave frequency, that energy flows through rods 30, and is radiated, only when current is applied to coils 50. A switch 80 permits current from a battery 81 to be applied to any one of the several coils 50, and thus to switch on the radiation from any one of the several rods 30. The rods 30 are coplanar but are arranged at various angles, the beam patterns of adjacent rods preferably overlapping. It will be understood that, with the arrangement described, the effect of a moving beam may be obtained by rotation of switch 80.

It will be understood that various high-speed beam-switching arrangements are possible in accordance with the invention. An arrangement for the rapid switching of beams from individual tilted radiators was described in connection with Figure 5. Similarly, two or more arrays may be tilted with respect to each other, and the arrays may be switched on and off sequentially at a rapid rate. One such arrangement is shown in Figures 6 and 7.

In Figures 6 and 7 a first array having a first beam direction comprises a plurality of ferrite rod radiators 30 coupled to a first waveguide section 84. A second array having a second beam direction comprises a plurality of radiators 30 coupled to a second waveguide section 86. Sections 84 and 86 meet in a junction 88. Junction 88 is coupled to another waveguide section 90 by means of a ferrite rod coupling element 92. A plane-polarized microwave signal is injected into section 90. A coil 94, connectable by a switch 96 to a battery 98, surrounds rod 92. It will often be desirable to cover rod 42 with a metal sleeve. When switch 96 is open the microwave energy reaching junction 88 has a certain plane of polarization and couples to the first array comprising waveguide 84 but not to the second array comprising waveguide 86. When switch 96 is closed the situation reverses; the plane of polarization of the energy flowing through rod 92 is rotated sufficiently so that the energy reaching junction 88 couples to the second array comprising waveguide 86 but not to the first array comprising waveguide 84.

It will be understood that other means of alternately energizing the radiating elements of two or more arrays may be employed.

It will also be understood that, if two of the systems shown in Figures 6-7 are placed at right angles to each other (rods 92 for each system being parallel), the resultant beam of the combined system can be pointed in any of four discrete directions by the appropriate energization of neither, one or the other, or both, of coils 94.

It will further be understood that, if desired, energy can be applied to two or more arrays simultaneously but in variable proportions.

Figure 8 shows a plurality of subarrays 102, 104, and 106 coupled to an energized waveguide section 108 by means of a plurality of ferrite rod coupling elements 112, 114, 116. The rods 30 are all perpendicular to the earth's surface, and the rods of each subarray lie in an east-west plane. A potentiometer 128 permits application of an adjustable current from a battery 130 to identical series-connected coils 124 and 126 that surround rods 114 and 116 respectively. An impedance 125 shunts coil 124. It will be understood that variation of the current through coils 124 and 126 will vary the phase of the microwave signal entering subarrays 104 and 106 and will thus vary the north-south direction of the resultant beam of the three subarrays. Control of east-west direction, if desired, can be accomplished by controlling the east-west direction of the beams from the several subarrays by application of techniques already described in connection with Figures 2, 3, and 4.

Figure 9 shows another arrangement for sequentially switching two noncoincident narrow beams on and off at high speed. Each of ferrite rod radiators 30 is coupled to one arm 131 or 132 of a waveguide element 133. Means 135 is provided for applying microwave energy to arms 131 and 132 alternately at a rapid switching rate. Skilled persons will be able to construct a suitable means 135 in the light of the disclosure relative to Figure 6 above. The beams from rods 30 are directed at, and reflected from, a suitable reflector 136 of parabolic or other shape.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of the invention as defined in the appended claims.

In connection with the embodiments shown in Figures 6, 7, and 9, it should be mentioned that the rotation-type switches incorporated in those embodiments are described in detail in copending application Serial No. 600,354, filed July 26, 1956, by Robert D. Hatcher. It will be understood that the two wave-guide arms between which the energy is switched should meet at a 90-degree angle for maximum efficiency, and that the ferrite rod (92 in Figure 6) should preferably be at the approximate center of the junction of the two waveguide arms.

A device incorporating certain features in common with certain embodiments of the present invention is described in copending application Serial No. 606,172, filed August 24, 1956, by Frank Reggia and Roy Conway Le Crow.

We claim:

1. A mechanically stationary microwave antenna array the beam of which may be shifted electrically, comprising: a section of waveguide; means for supplying microwave energy of frequency f_0 to said waveguide; first and second apertures in the wall of said waveguide; first and

second ferrite rod radiators each having an input end and an output end, the input ends being coupled to said first and second apertures respectively; and electrical means for applying a magnetic field to at least one of said ferrite rod radiators so as to vary a characteristic of the radiation from the output end of said second radiator relative to the corresponding characteristic of the radiation from the output end of said first radiator.

2. The invention according to claim 1, said electrical means comprising: a coil around said second rod; and means for supplying a variable current to said coil, thereby applying a magnetic field to said rod.

3. The invention according to claim 2, there being additionally provided a section of waveguide coaxially surrounding a portion of said second rod, the dimensions of said waveguide being such in relation to f_0 that the propagation of substantial microwave energy through said section is dependent on the application of current to said coil.

4. The invention according to claim 2 so constructed and arranged that substantial microwave energy is propagated through and radiated from said second rod when said coil is not energized, as well as when said coil is energized.

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