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ELECTROMAGNETICALLY STEERED MICROWAVE ANTENNA

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2 Sheets-Sheet 1

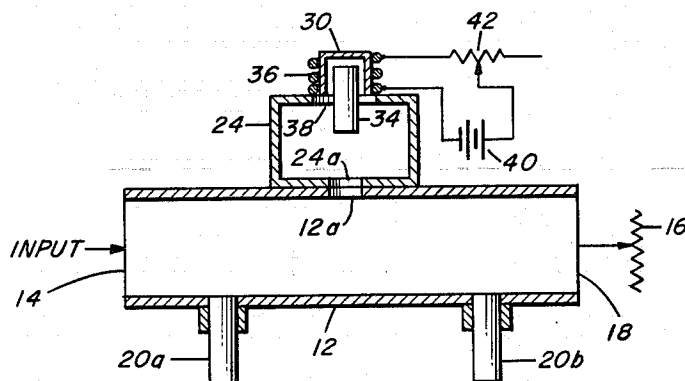


Fig. 1.

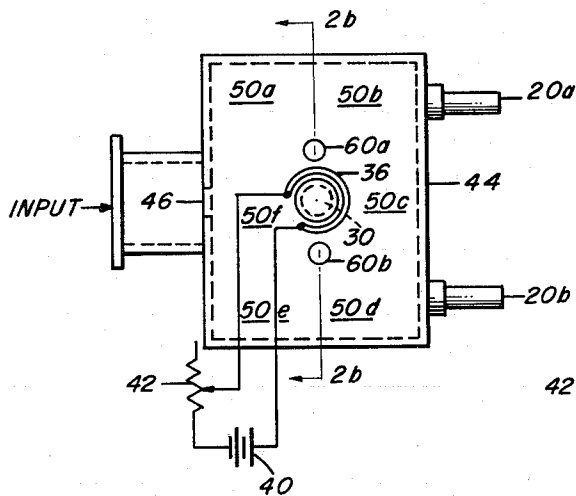


Fig. 2a.

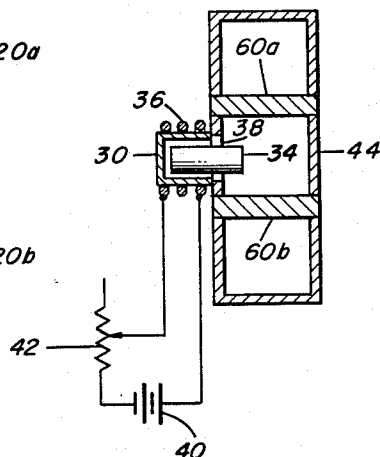


Fig. 2b.

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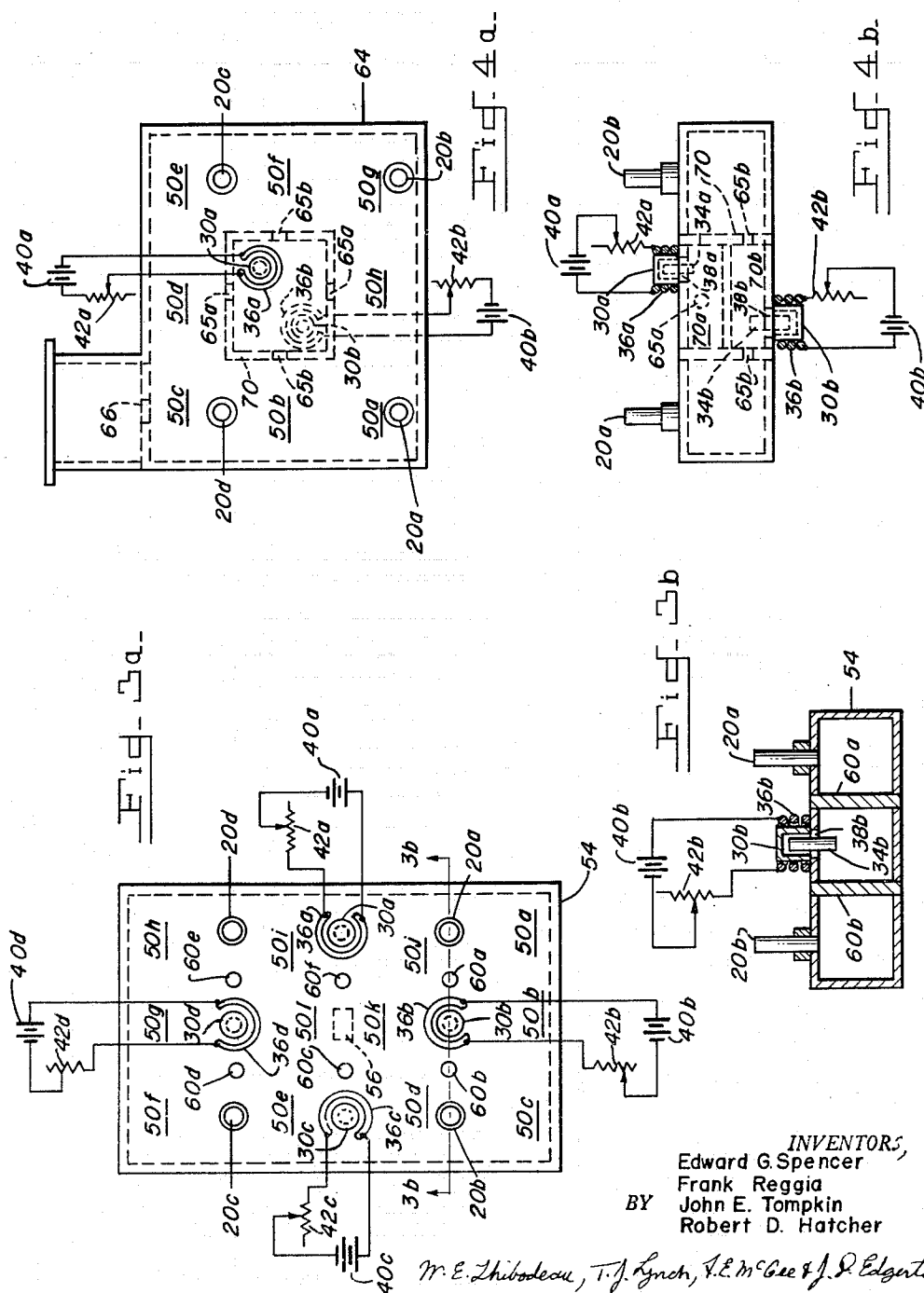
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ELECTROMAGNETICALLY STEERED MICROWAVE ANTENNA

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Application May 2, 1957, Serial No. 656,733

8 Claims. (Cl. 343—778)

(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 electrical control of microwave structures in general and more particularly to microwave cavity means for electrically varying the microwave length along a microwave structure at a predetermined place.

In preferred forms of the invention, variations in the electrical length at microwave frequencies, along a microwave structure are obtained by electrically varying the resonant frequency of a resonant microwave cavity coupled to the microwave structure at the place where the change in microwave length is desired. The resonant microwave cavity may be external to the microwave structure or else may be internal, that is the resonant microwave cavity may be an elementary resonant cavity forming part of the microwave structure. By "resonant cavity" is meant a cavity in a system having an operating frequency approximately equal to the resonant frequency of the cavity. Because small changes in the resonant frequency of such a resonant cavity produce large changes in the reactance presented by the cavity, large variations in microwave length are obtained at the place of coupling. These large variations in microwave length may be advantageously used in microwave antenna arrays. By varying the microwave length between two radiators, the phase of the energy radiated by one radiator can be varied relative to the phase of the energy radiated by the other radiator.

One object of the invention is to provide improved microwave control means for electrically varying the microwave length along a microwave structure at a predetermined place.

Another object is to provide improved means for varying the resonant frequency of a resonant microwave cavity.

A further object is to provide improved microwave antenna arrays having electrically controlled means for rapidly and conveniently varying the phases between the energy radiated by the radiators relative to one another.

A further object of this invention is to provide improved microwave antenna arrays having electrically controlled means for varying the phases between the energy radiated by the radiators relative to one another over considerably larger ranges than heretofore obtainable.

Still another object is to provide improved means for exciting and controlling the power radiated by microwave radiating elements.

The specific nature of the invention as well as other objects, uses and advantages thereof will clearly appear from the following description and from the accompanying drawing, in which:

Figure 1 is a simplified sectional and schematic representation of a waveguide-fed linear array having external microwave cavity means for electrically varying

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the relative phase between the energy radiated by the radiators, in accordance with the invention.

Figure 2a shows a cavity-fed linear array having internal microwave cavity means for electrically varying the relative phase between the energy radiated by the radiators, in accordance with the invention.

Figure 2b is a cross-sectional view taken along the line 2b—2b of Figure 2a.

Figure 3a shows a rectangular cavity-fed array having internal microwave cavity means for electrically varying the phases between the energy radiated by the radiators relative to one another, in accordance with the invention.

Figure 3b is a cross-sectional view taken along the line 3b—3b of Figure 3a.

Figure 4a is a top view of a rectangular cavity-fed array having external microwave cavity means for electrically varying the phases between the energy radiated by the radiators relative to one another, in accordance with the invention.

Figure 4b is a front view of Figure 4a.

In Figure 1, a section of waveguide 12 is adapted to be supplied with microwave energy at one end 14 and is terminated in a matching impedance 16 at the other end 18.

Two ferrite radiating elements 20a and 20b are placed to form a linear array and are coupled to the waveguide 12 in accordance with well known practice.

A resonant cavity 24 is coupled to the waveguide 12 at a place intermediate to the radiators 20a and 20b by coincident apertures 12a and 24a in the waveguide 12 and resonant cavity 24 respectively. A metal cup 30 is mounted on the cavity 24 and has a ferrite rod 34 extending from the interior of the metal cup 30 through an aperture 38, the metal cup 30 and aperture 38 being located so that the ferrite rod 34 couples at a position of maximum magnetic field. A coil 36 surrounds the metal cup 30 and is connected to a variable current source comprising a battery 40 and a current control potentiometer 42.

A change in the current flowing through the coil 36 changes the magnetic field applied to the ferrite rod 34 and causes a change in the resonant frequency of the resonant cavity 24. A change in the resonant frequency of the resonant cavity 24 alters the impedance presented to the waveguide 12 at its aperture 12a, producing a change in the microwave length between the radiators 20a and 20b and resulting in a change in the relative phase between the energy radiated by the radiators 20a and 20b. The relative phase shift obtained between the radiators 20a and 20b is equivalent to that produced by applying the same magnetic field to a much larger piece of ferrite not placed in a resonant cavity. Relative phase shifts considerably higher than previously obtainable are now possible.

Figures 2a and 2b show views of a cavity-fed linear array having internal microwave cavity means for electrically varying the phase of energy radiated by the radiators relative to one another, in accordance with the invention. A resonant TE_{203} mode cavity 44 is divided into six elementary resonant cavities 50a, 50b, 50c, 50d, 50e, and 50f by shorting posts 60a and 60b placed at points of zero electric current and zero electric and magnetic fields within the TE_{203} mode cavity 44. Center lines drawn through the shorting posts 60a and 60b parallel to the walls of the TE_{203} mode cavity indicate the elementary resonant cavities 50a, 50b, 50c, 50d, 50e, and 50f. Microwave energy is supplied to the TE_{203} mode cavity 44 through an aperture 46. Two ferrite radiating elements 20a and 20b are placed to form a linear array and are coupled to the energy in the TE_{203} cavity 44 in accordance with well known practice.

A metal cup 30 is mounted on the TE_{203} mode cavity

44, and a ferrite rod 34 extends from the interior of the TE₂₀₃ mode cavity 44 into the interior of the metal cup 30 through an aperture 38. The metal cup 30 and aperture 38 are located so that the ferrite rod 34 couples to the elementary resonant cavities 50c and 50f at a position of maximum magnetic field. A coil 36 surrounds the metal cup 30 and is connected to a variable current source comprising a battery 40 and a current control potentiometer 42.

A change in the current flowing through the coil 36 changes the magnetic field applied to the ferrite rod 34 and causes a change in the resonant frequency of the elementary resonant cavities 50c and 50f to which the ferrite rod 34 is coupled. A change in the resonant frequency of the elementary resonant cavity 50c changes the microwave length appearing between the radiators 20a and 20b and results in a change in the relative phase between the energy radiated by the radiators 20a and 20b.

The cavity-fed array as basically illustrated in Figures 2a and 2b has the advantage that each of the elementary resonant cavities will have the same energy within the elementary cavity even though the resonant mode cavity is fed at only one place. This advantage of cavity-fed arrays permits convenient and simple adjustment of the power radiated by each radiating element. This advantage becomes more greatly apparent as the number of radiating elements is increased. The power radiated by each radiator of a waveguide-fed array as basically illustrated in Figure 1 is more difficult to adjust because the amplitude and phase of the energy reaching each radiator will depend upon the amount of energy absorbed by the previous radiators.

The particular cavity-fed array and cavity control means of Figures 2a and 2b has a further advantage. Because the shorting posts 60a and 60b furnish tight boundary conditions operation in the TE₂₀₃ mode cavity 44 is restricted to a single well defined and especially chosen cavity mode. Therefore, even for large changes induced in the elementary resonant cavities by changes in the magnetic field applied to the ferrite rod 34, the mode of operation within the TE₂₀₃ cavity 44 remains substantially the same.

The principles and advantages of the linear cavity-fed array having internal microwave cavity control means as in Figures 2a and 2b can be extended to a rectangular cavity-fed array as shown in Figures 3a and 3b. In Figures 3a and 3b a TE₃₀₄ mode cavity 54 is divided into twelve elementary resonant cavities 50a, 50b, 50c, 50d, 50e, 50f, 50g, 50h, 50i, 50j, 50k, 50l by shorting posts 60a, 60b, 60c, 60d, 60e, and 60f placed at points of zero current and zero electric and magnetic fields within the TE₃₀₄ mode cavity 54. Center lines drawn through the shorting posts 60a and 60b parallel to the walls of the TE₃₀₄ mode cavity 54 indicate the elementary resonant cavities 50. Microwave energy is supplied to the TE₃₀₄ mode cavity 54 through an aperture 56. Four ferrite radiating elements 20a, 20b, 20c, and 20d are placed to form a rectangular array and are coupled to the TE₃₀₄ cavity 54 in accordance with well known practice.

Four metal cups 30a, 30b, 30c, and 30d, mounted on the TE₃₀₄ mode cavity 54 between the radiators, have ferrite rods 34a, 34b, 34c, and 34d extending from the interior of the TE₃₀₄ cavity 54 into the metal cups 30a, 30b, 30c, and 30d through apertures 38a, 38b, 38c, and 38d respectively, the metal cups 30 and apertures 38 being placed so that each ferrite rod 34 is coupled at a position of maximum magnetic field to an elementary cavity 50 located between a pair of radiators 20. Coils 36a, 36b, 36c and 36d surround metal cups 30a, 30b, 30c and 30d respectively, each of the coils 36 being connected to its own variable current source comprising a battery 40 and a current control potentiometer 42.

The operation of the rectangular cavity-fed array having internal microwave cavity control means as in Figures 3a and 3b is substantially the same as the opera-

tion of the linear cavity-fed array of Figures 2a and 2b. That is, by varying the current through the coils 36, the phases between the energy radiated by the radiators 20 may be varied relative to one another. Skilled persons will be able to provide various equivalents of the current control means comprising batteries 40 and potentiometers 42 that will permit the relative phases to be varied in accordance with any desired periodic or aperiodic program, and at very high rates of speed.

The cavity-fed rectangular array of Figures 4a and 4b illustrates the use of external cavity control means for varying the phases between the energy radiated by the radiators relative to one another. In Figures 4a and 4b a TE₃₀₃ mode cavity 64 is divided into eight elementary resonant cavities 50a, 50b, 50c, 50d, 50e, 50f, 50g, and 50h by a microwave structure 70 symmetrically located at the center of the TE₃₀₃ mode cavity 64. The microwave structure 70 comprises two resonant cavities 70a and 70b having coupling irises 65a and 65b. Four ferrite radiators 20a, 20b, 20c, and 20d are coupled to elementary cavities 50a, 50g, 50e and 50c respectively to form a rectangular array in accordance with well known practice. Microwave energy is supplied to the TE₃₀₃ mode cavity through an aperture 66.

Metal cups 30a and 30b, mounted on cavities 70a and 70b respectively, have ferrite rods 34a and 34b extending from the interior of the TE₃₀₃ cavity 64 through apertures 38a and 38b respectively. Coils 36a and 36b surround metal cups 30a and 30b respectively, each of the coils 36a and 36b being connected to variable current sources comprising a battery 40a and potentiometer 42a for the coil 36a and a battery 40b and potentiometer 42b for the coil 36b.

By changing the current applied to coil 36a, a change in the resonant frequency of cavity 70a is effected causing a change in the microwave length between the two radiators 20a and 20b and the two radiators 20d and 20c. A change in the current applied to coil 36b effects a similar change in the resonant frequency of cavity 70b, permitting control of the microwave length between the two radiators 20a and 20c, and the two radiators 20b and 20d. This type of rectangular array has the advantage over the rectangular array of Figures 3a and 3b of allowing control of the microwave length between two pairs of radiators by a single resonant cavity.

The difference between the external and internal cavity means for controlling the microwave length is that in the internal case, control of microwave length is obtained by controlling the resonant frequency of one of the elementary resonant cavities forming part of the resonant cavity structure while in the external case, control of microwave length is obtained by controlling the resonant frequency of an external resonant cavity coupled to the resonant cavity structure at the place where the change in microwave length is desired. Since the external cavity can be coupled at a number of places to the same resonant cavity structure or to different cavity structures, a greater versatility can be obtained.

Although the linear and rectangular arrays have been described using ferrite radiating elements, the same results can be obtained for other types of radiating elements, for example, slot radiating elements. Furthermore, the arrays described are only intended to illustrate the possibilities of the invention and much larger and more complex arrays may be constructed within the scope of the invention.

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.

We claim:

1. A linear, mechanically stationary microwave antenna array the beam of which may be varied electrically, comprising in combination: a resonant cavity structure; means for supplying microwave energy to said resonant

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cavity structure; means for dividing said resonant cavity into elementary resonant cavities; two radiators placed on said resonant cavity structure to form a linear array; a metal cup mounted on said resonant cavity structure between said radiators; a ferrite rod extending from the interior of said resonant cavity structure through an aperture into the interior of said metal cup, said aperture and said metal cup being placed so that said ferrite rod is coupled to an elementary cavity located between said radiators; a coil surrounding said metal cup; and means for applying a variable current to said coil thereby varying the phases between the energy radiated by said radiators relative to one another.

2. A rectangular, mechanically stationary microwave antenna array the beam of which may be varied electrically, comprising in combination: a resonant cavity; means for supplying microwave energy to said resonant cavity; means for dividing said resonant cavity into elementary cavities; four radiators placed on said resonant cavity structure to form a rectangular array; four metal cups mounted on said resonant cavity structure, one metal cup being mounted between each pair of radiators; four ferrite rods, each rod extending from the interior of said resonant cavity structure through an aperture into the interior of one of said metal cups, said metal cups and apertures being placed so that each ferrite rod is coupled to an elementary cavity located between a pair of radiators; a coil surrounding each metal cup; and means for applying a variable current to each of said coils thereby varying the phase between the energy radiated by said radiators relative to one another.

3. A mechanically stationary microwave antenna array the beam of which may be varied electrically, comprising in combination: a resonant cavity microwave structure; means for supplying microwave energy to said microwave structure; radiators coupled to said microwave structure; and microwave cavity means for electrically varying the microwave length between said radiators so that the phases between the energy radiated by said radiators are varied relative to one another, said microwave cavity means for varying the microwave length between said radiators comprising means for dividing said resonant cavity into elementary resonant cavities, and electrically controlled means for varying the resonant frequencies of predetermined elementary resonant cavities, said predetermined elementary cavities being chosen between said

radiators so that variations in the resonant frequencies of said predetermined elementary cavities varies the phases between the energy radiated by said radiators relative to one another.

5 4. The invention in accordance with claim 3 wherein said means for dividing said resonant cavity structure into elementary resonant cavities comprises: shorting posts placed at points of zero electric current and zero electric and magnetic fields within said resonant cavity.

10 5. The invention in accordance with claim 3 wherein the resonant frequency of each predetermined elementary resonant cavity is varied by electrically controlled means comprising: a ferrite piece coupled to said predetermined elementary cavity; and electrically controlled means for applying a variable magnetic field to said ferrite piece.

15 6. The invention in accordance with claim 3 wherein the resonant frequency of each predetermined elementary resonant cavity is varied by electrically controlled means comprising: a metal cup mounted over said predetermined elementary cavity; a ferrite rod extending from the interior of said predetermined elementary cavity through an aperture into the interior of said metal cup; and electrically controlled means for applying a variable magnetic field to said ferrite rod.

20 7. The invention in accordance with claim 5 wherein said electrically controlled means for applying a variable magnetic field to said ferrite rod comprises: a coil surrounding said metal cup; and means for applying a variable current to said coil.

25 8. The invention in accordance with claim 7 wherein said means for dividing said resonant cavity structure into elementary resonant cavities comprises: shorting posts placed at points of zero electric current and zero electric and magnetic fields within said resonant cavity.

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