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HIGH EFFICIENCY SCANNING MILLIMETER WAVELENGTH ANTENNA

Filed Dec. 11, 1967

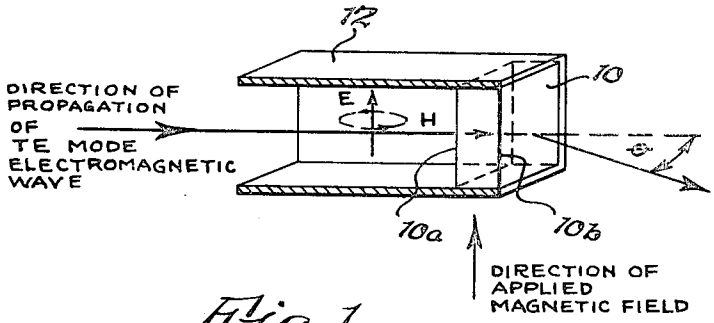


Fig. 1.

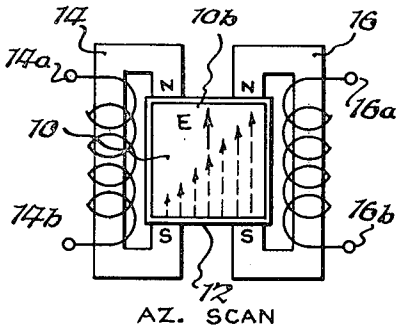


Fig. 2.

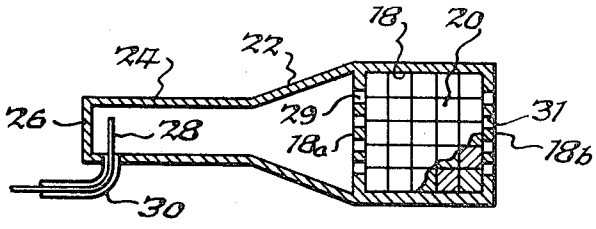


Fig. 3.

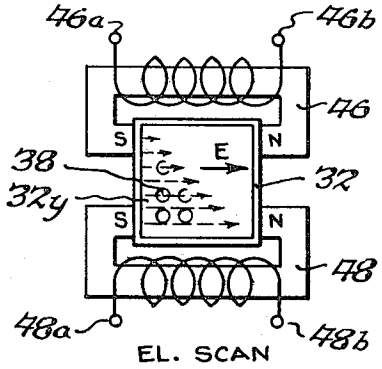


Fig. 6.

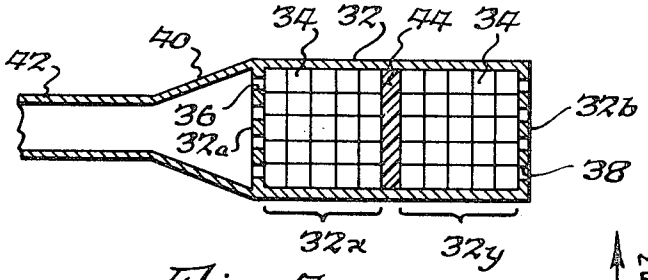


Fig. 4.

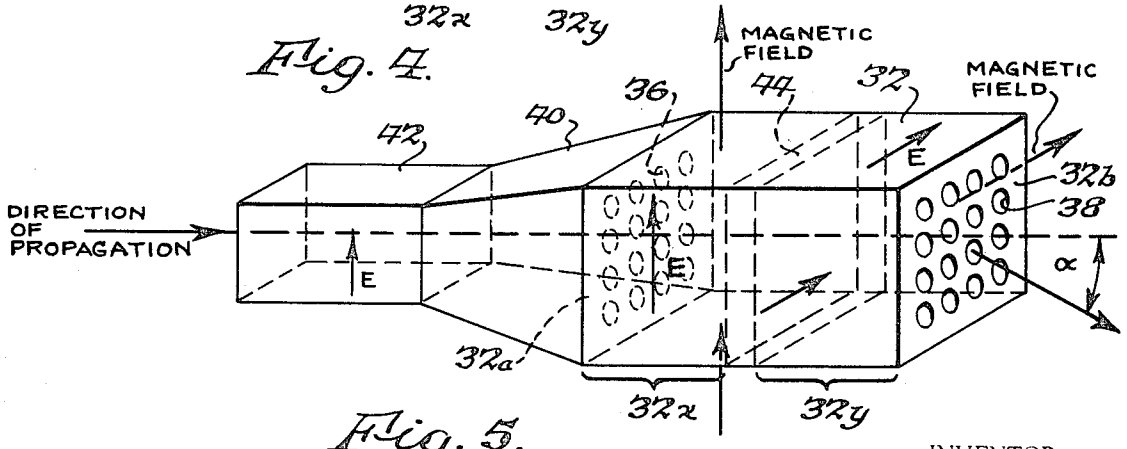


Fig. 5.

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HIGH EFFICIENCY SCANNING MILLIMETER WAVELENGTH ANTENNA

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Int. Cl. H01q 3/26, 13/00, 13/10
U.S. Cl. 343—768 12 Claims

ABSTRACT OF THE DISCLOSURE

An electronic scanning millimeter wavelength antenna comprising a ferrite filled resonant cavity having energy input and output coupling holes in opposite sides of the cavity. TE mode energy is directed into the cavity by a radiating horn, and a magnetic field is applied to the cavity in the same direction as the electric field vector of the energy propagating therethrough. The field has a flux density gradient across the cavity which causes a phase shift taper. Variation of the field gradient enables one dimensional scanning of the millimeter wave energy emerging from the output coupling side of the cavity. Two dimensional scanning is achieved by placing a half wave plate in the cavity midway between the input and output coupling sides, and applying orthogonal magnetic fields respectively to the partitioned sections of the cavity.

BACKGROUND OF THE INVENTION

This invention relates to electromagnetic wave scanning devices and more particularly to a millimeter wavelength antenna with electronically controlled scanning of improved efficiency.

The small size and narrow beamwidth of millimeter wavelength antennas make them extremely attractive for many applications. For example, millimeter systems offer substantial potential applications to space missions involving functions of communications, navigation, surveillance and reconnaissance. This potential stems in part from the high antenna gains achieveable from the small radiating apertures at millimeter wavelengths. The narrow beamwidths necessarily associated with such high gain antennas, on the other hand, aggravate the problems of search and acquisition because of the great increase in the number of beam positions for a given solid angle of search. A V-band system, for example, operating at 50 gHz. would involve one hundred times as many beam positions at each terminal as would a C-band system operating at 5 gHz. with the same size radiating aperture. It is readily ascertained that the ability to scan large angles in a rapid and inertialess manner is a vital requirement for space applications where only coarse a priori positional knowledge of the second terminal or target is available. For communication acquisition and radar applications a high gain scanned antenna is required having scan speeds in the order of microseconds.

These requirements obviously preclude the use of mechanical scanning methods, which have relatively high mechanical inertia, slow scan speeds and short term reliability. Consequently, electronically controlled scanning appears to be the most desirable approach.

The extrapolation or adaptation of conventional microwave phased array techniques to millimeter wavelengths, however, becomes increasingly costly and technically impractical with increasing frequency of operation in the millimeter domain. For example, in order to scan a 45° x 45° sector with an array of 1° beamwidth antennas and achieve 40 db antenna gain, approximately 15,000 radiating elements would be required. Moreover, the majority of discrete element phased arrays, which are limited by

their nature to certain applications, would necessarily involve many thousands of millimeter phase shifters and a myriad of RF connectors, power dividers and/or directional couplers and sections of millimeter transmission lines. Setting aside the state-of-the-art problems of realixing effective and reproducible millimeter components, there still remains the problem of fabricating and packaging the components into the over-all antenna assembly at a realistic cost.

An approach toward meeting these problems of millimeter wave antenna scanning by using a free space mode ferrite scanner is described in U.S. Pat. No. 3,369,242, assigned to the assignee of the present application. A free space mode, circularly polarized wave is passed through a ferrite disk which is subjected to a magnetic field applied parallel to the direction of propagation and having a flux density gradient across the beam traversing the ferrite. The magnetic field affects the permeability and index of refraction of the ferrite to thereby cause a phase shift in the wave traversing the disk, and the flux density gradient of the field causes this phase shift to be linearly tapered across the beam. As a result, the beam emerging from the ferrite disk has a phase front at an angle to the original direction of propagation, and scanning of the beam can be accomplished by varying the magnitude of the field. Two dimensional scanning is provided by arranging electromagnets orthogonally around the periphery of the ferrite disk.

Although this free space mode scanner provides advantages of reduced complexity, cost, size and weight, it has some significant shortcomings. Relatively strong magnetic fields and thus large electromagnet control currents are required to provide the desired beam scanning, a scanning power of 2 watts being typical. As a consequence, scanning efficiency is low, and aperture size, hence the narrowness of beamwidth, is restricted by practical power availability considerations. A 4° beamwidth is about the narrowest obtainable in practical embodiments, due to the maximum size limitations on the aperture.

SUMMARY OF THE INVENTION

The present invention provides a significant improvement over the above-described free space mode ferrite scanner by substantially increasing scanning efficiency, and thereby significantly reducing the magnetic field strength required. Consequently, larger apertures are possible, with attendant narrow beamwidths.

Briefly, the scanning antenna according to the present invention comprises a ferrite filled resonant cavity which is energized by a source of linearly polarized millimeter wave energy coupled to the cavity input by means of a radiating horn or some other waveguide structure. Energy is coupled out of the cavity by means of an array of regularly spaced coupling holes in one of the cavity sidewalls. Scanning is controlled by subjecting the cavity to a variable magnetic field applied parallel to the direction of the millimeter wave electric field vector and having a flux density gradient across the cavity. The magnetic field affects the permeability of the ferrite so as to cause a phase shift in the energy traversing the cavity proportional to the magnitude of the applied field. Due to the resonant nature of the cavity, the millimeter wave energy is reflected back and forth between the cavity sidewalls, each traversal adding an additional phase shift. Consequently, a small applied field results in a large phase shift, the value of magnetic field strength necessary to provide a given phase shift being reduced by approximately the Q of the cavity.

The flux density gradient of the applied field causes the phase shift to be tapered across the cavity. As a consequence, the phase front of the millimeter wave energy

emerging from the cavity is deflected from the original direction of propagation. Variation of the applied flux density gradient, therefore, enables one dimensional scanning of this emerging energy.

Two dimensional scanning is achieved by inserting a half wave plate in the cavity midway between the input and output coupling sidewalls so as to partition the cavity into two sections. The magnetic field is applied to the input side cavity section in the manner described for the one-dimensional case. Since the half wave plate rotates the millimeter wave electric field vector by 90°, however, an orthogonal field is applied to the output side cavity section in a direction parallel to the electric field vector in that section and with a flux density gradient across that section of the cavity. This arrangement has the advantage of eliminating cross talk problems between scan directions, since the orthogonal magnetic fields produce no effect on the undesired polarization.

BRIEF DESCRIPTION OF THE DRAWINGS

This invention will be more fully described hereinafter in conjunction with the accompanying drawings, in which:

FIG. 1 is a simplified sectional-perspective diagram of a magnetically controlled ferrite body in wave guide which illustrates how azimuth scanning of a TE mode wave may be accomplished;

FIG. 2 is a diagrammatic view of the output end of the azimuth scanning structure of FIG. 1 which illustrates the flux density gradient and phase shift taper effects across the ferrite body and a preferred arrangement of electromagnets to produce this effect;

FIG. 3 is a cross-sectional view of an embodiment of the invention for providing one dimensional scanning;

FIG. 4 is a cross-sectional view of an embodiment of the invention which includes a ferrite loaded cavity partitioned into input and output sections for providing two dimensional scanning;

FIG. 5 is a perspective view of the structure of FIG. 4, with some of the internal features illustrated by dashed lines; and,

FIG. 6 is a diagrammatic view of the output end of the structure of FIGS. 4 and 5 which illustrates the flux density gradient and phase shift taper effects across the output section of the cavity for providing elevation scanning, and a preferred arrangement of electromagnets to produce this effect.

DETAILED DESCRIPTION OF THE INVENTION

To enable a full understanding of the construction and operation of the invention, a brief discussion of the physical properties involved will first be presented. The problem of steering an electromagnetic wave is one of altering the phase front of the wave in such a manner as to change its direction of propagation. This can be accomplished by advancing or retarding the phase of one portion of the wave with respect to another. If the incident wave is plane, a progressive linear phase change must occur across the wave front if the beam shape of the output wave is to be preserved.

According to the present invention, a phase change is produced by passing the incident wave through a dielectric having controllable properties. Specifically, the concept is to vary the index of refraction of the dielectric, such as a body of ferrimagnetic material, by electronically controlled means.

Ferrimagnetic materials fall into three general classes, cubic ferrites, garnets, and hexagonal ferrites. Ferrites are characterized by the general chemical composition $MO.Fe_2O_3$ where M is a divalent metal such as iron, magnesium, zinc, nickel, or manganese. The element M in the ferrite may be any of these divalent metals except iron and may be placed in the ferrite in combination or singly.

The effect of ferrimagnetic materials on an electromagnetic wave lies in the interaction of the wave with unpaired electrons in the ferrite. When a magnetic field is applied to the ferrite, the unpaired electrons assume a fixed orientation to that field and behave in a similar manner to a gyroscope. The resonant frequency of the ferrite is then

$$f=\gamma H_a \tag{1}$$

where

f=resonant frequency in mc.
γ=the absolute value of the gyromagnetic ratio (2.8 mc. per oersted)
H_a=applied field in oersteds.

At resonance, the electromagnetic energy is strongly absorbed by the ferrite and is dissipated as heat in the crystal lattice. Because the electrons are acting as a gyroscope, the electromagnetic wave can interact with the ferrite only when the magnetic vector of the wave is executing the same motion. It is necessary, therefore, that the wave impinging on the ferrite have a circularly polarized magnetic field which has the same sense of rotation as does the electron in the static magnetic field. For example, for a TE mode wave having a circularly polarized magnetic field in a plane perpendicular to its electric field vector, the static magnetic field is applied to the ferrite in a direction parallel to that of the electric field vector.

In order to better define the behavior of a ferrite, it is convenient to express its permeability as a function of a steady state magnetic field. The relative permeability of the cubic ferrite or garnet is near unity when no field is applied. This, of course, is to be expected since the elements are in random orientation in the ferrite. Upon application of a field the permeability decreases and, as the field is increased, will go to zero thence to negative values. In this latter region, the ferrite is biased to resonance and large absorption results. For values of magnetic field which are smaller than the resonance value, however, the permeability can be varied. Because interaction can take place only when the electromagnetic wave has a magnetic field component which is circularly polarized with the same sense as the electron gyroscope, this behavior of the permeability will have an effect only upon that sence of magnetic field polarization. The permeability for the opposite sense of polarization is essentially constant and equal to unity.

The index of refraction of any material is defined as the ratio of the velocity of a wave in free space to that in the material. Therefore, if the index of refraction in a given thickness of material can be changed, its electrical length will vary and a phase shift will result. The index of refraction n has the following relationship:

$$n=\sqrt{\mu\epsilon} \tag{2}$$

where

μ=permeability
ϵ=permittivity.

The permittivity or dielectric constant of the ferrite remains constant under various field conditions. The index of refraction, therefore, will vary as the square root of the permeability. It will be found convenient to allow the permeability to vary between unity and $1/\epsilon$ since that will cause the index of refraction to vary from $\sqrt{\epsilon}$ to 1. When the index is unity, the velocity of propagation in the ferrite is equal to that of free space and no refraction results.

In order that this variable index of refraction acocmplish beam scanning, it is necessary that the ferrite introduce a progressive phase shift across the width of the beam. This requisite phase shift taper across the beam is accomplished in the present invention as illustrated by the simplified diagrams of FIGS. 1 and 2. FIG. 1 shows a ferrite body **10**, in the form of a plane parallel plate, positioned within and at the right end of a waveguide **12**, which is directing TE mode electromagnetic wave energy

toward the ferrite body. The electric (E) field of the linearly polarized wave energy in guide **10** has its vector in the indicated direction. Associated with this E field is a magnetic (H) field, which is circularly polarized in a plane orthogonal to the E field vector, as illustrated. The structure is arranged such that the direction of propagation of the electromagnetic wave incident upon face **10***a* of the ferrite is substantially normal to that face; that is, the angle of incidence at face **10***a* is 0°.

A source of magnetic field, represented in FIG. 2 by electromagnets **14** and **16** having terminals **14***a*, **14***b* and **16***a* and **16***b*, respectively, connected to respective variable current sources, is arranged to subject the ferrite to a magnetic field which is parallel to the direction of the E field vector of the wave impinging on face **10***a*, as illustrated. The electromagnets are also arranged to provide a magnetic field having a flux density gradient across the beam traversing the ferrite. More specifically, the magnetic field is tapered linearly across the width of the ferrite so that the phase delay is varied across the beam and the emerging energy from face **10***b* of the ferrite, which is parallel to face **10***a*, will have a phase front at an angle θ to the original direction of propagation in the azimuth plane. The tapered magnetic field, or flux density gradient, is illustrated diagrammatically in FIG. 2 by the arrows of increasing length from left to right across the ferrite body **10**.

FIG. 2 also shows a preferred arrangement of the electromagnets for obtaining this tapered field effect. Electromagnet **14** is positioned on the left side of ferrite body **10** with its north and south poles disposed on the top and bottom sides respectively, near the left edges of the ferrite. The north and south poles of electromagnet **16** are disposed in like manner on the right side of the ferrite. The field taper direction illustrated in FIG. 2 is obtained by applying a low current through terminals **14***a* and **14***b* to produce a relatively weak field across the ferrite between the poles of electromagnet **14**, and by applying a large current throuhg terminals **16***a* and **16***b* to produce a much stronger field between the opposite poles of electromagnet **16**. By appropriate adjustment of the electromagnet control currents the desired flux density gradient, increasing to the left, can be produced. To achieve azimuth scanning, the currents applied to the terminals of electromagnets **14** and **16** are appropriately varied in magnitude to obtain the desired variation in respective field strengths and, hence, a variation of the flux density gradient. That is, the gradient can be varied as a function of applied control currents to have selected positive or negative slopes. As previously discussed, variations in the flux density gradients cause the permeability, and hence the index of refraction to be varied, thereby varying the azimuth angle θ of the emerging beam.

The present invention employs the above described properties, but generally enhances the efficiency of scanning by enclosing the ferrite in a resonant cavity, thereby taking advantage of the multiple reflections of wave energy in the cavity to correspondingly multiply the phase shift produced for a given applied magnetic field strength. A preferred embodiment of the invention for providing one dimensional scanning is illustrated by the cross-sectional diagram of FIG. 3. The scanning antenna comprises a resonant cavity **18** filled with a ferrite material **20** and arranged to be energized by a radiating horn **22**. Preferably, the ferrite is in the form of small cubes, of the order of ½ inch on a side, to reduce hysteresis effects. The horn is adapted to be connected to a source of electromagnetic wave energy so as to be excited in a TE mode. For example, as shown in FIG. 3, such TE mode excitation may be provided by attaching to the throat of the horn a section of waveguide **24** having an end plate **26** and a vertical exciting rod **28**. The vertical rod can be energized by connecting it through a coaxial cable **30** to a signal generator (not shown). In the preferred application, this signal generator comprises a millimeter wavelength transmitter.

The sidewalls of cavity **18** are constructed of a material suitable for containing and reflecting millimeter wave energy, such as brass or aluminum, and the cavity is dimensioned to operate in a $TE_{l, m, n}$ mode, where *l*, *m* and *n* are numbers greater than 3. The waveguide and horn are also preferably constructed of brass or aluminum. Energy is coupled into the cavity from horn **22** by means of a large number of tiny coupling holes **29** arranged in a regularly spaced array in side **18***a* of the cavity. The opposite and parallel side **18***b* of the cavity contains a similar array of regularly spaced holes **31** for coupling energy from the cavity into free space. Cavity **18**, therefore, comprises a millimeter wavelength Fabry-Perot interferometer, with sides **18***a* and **18***b* being the parallel plate reflectors, and the means for coupling into and out of the resonance region between the plates being provided by the arrays of holes **29** and **31**. It is to be understood, of course, that the coupling hole arrays illustrated in FIGS. 3, 4 and 5 are merely diagrammatic representations and not to scale.

The design and analysis of hole gratings, such as sides **18***a* and **18***b*, for providing suitable reflectors and preserving the large Q value therebetween, is quite thoroughly discussed in the following references: (a) W. Culshaw, "Reflectors for a Microwave Fabry-Perot Interferometer," IRE Transactions on Microwave Theory and Techniques, vol. MTT–7, pp. 221–228, April 1959; (b) W. Culshaw, "High Resolution Millimeter Wave Fabry-Perot Interferometer," IRE, vol. MTT–8, pp. 182–189, March 1960; (c) W. Culshaw, "Resonators for Millimeter and Sub-Millimeter Wavelengths," IRE, vol. MTT–9, pp. 134–144, March 1961; and (d) P. D. Coleman, "State of the Art Background and Recent Developments—Millimeter and Sub-Millimeter Waves," IEEE, vol. MTT–11, pp. 271–288, September 1963 at pp. 283–284.

Reference (a) discusses application of the microwave Fabry-Perot interferometer at millimeter wavelengths, particularly emphasizing the requirement for reflectors of high reflectivity, small absorption and adequate size. A particularly suitable reflector design for very small wavelengths is shown to be the hole grating, comprising a series of circular holes regularly spaced in a thin metal sheet. A brief analysis of the planar hole grating, as a function of hole size and spacing, and stacking of gratings, is presented on p. 226. Other reflector forms found to be suitable are stacked dielectric plates, and stacked planar or rod gratings.

Reference (b) describes further development of these reflector designs on pp. 185 and 186, with a photograph of a perforated hole grating being shown in FIG. 5. Reference (c), at pp. 136 and 137, analyzes the planar millimeter wave interferometer as a resonant cavity. Also discussed are the use of curved or cylindrical hole grating reflectors to provide focused Fabry-Perot resonators, and the design of biconical spherical resonators. Finally, reference (d) presents a survey of the state of the art developments in millimeter wave resonators, including a variety of reflector shapes and coupling methods.

Returning to FIG. 3, energization of rod **28** causes TE mode electromagnetic energy to be launched along waveguide **24** toward the radiating horn region. The horn is arranged with its mouth facing side **18***a* of the cavity so as to direct this TE mode energy into cavity **18** through the input coupling holes **29**. The E field vector of the energy in the waveguide, horn and cavity is oriented in the upward direction with an orthogonal circularly polarized H field, as indicated in FIGS. 1 and 2. The cavity is tuned to be resonant at the frequency of the electromagnetic wave energy directed into it from the horn. This tuning means is not shown in FIG. 3; however, it may comprise any of a number of methods well known in the art, e.g., a moveable side, or insertion of a slug.

One dimensional scanning in the azimuth plane is obtained by subjecting cavity **18** to a magnetic field applied

in the same direction as the E field vector of the energy propagating through the cavity and having a flux density gradient across the cavity, as illustrated in the output end view diagram of FIG. 2. A preferred method of producing this magnetic field is to arrange electromagnets about cavity **18** as shown in FIG. 2 with respect to ferrite body **10**. Application of a magnetic field in this manner to the ferrite material **20**, within the appropriate field strength range to vary permeability and in a direction parallel to the E field vector, will, as previously discussed, cause an interaction with the electromagnetic wave which results in a phase shift of the millimeter wave energy proportional to the magnitude of the field. Because of the resonant nature of the cavity, the energy is bounced back and forth between walls **18***b* and **18***a*. Each transversal adds an additional phase shift, so that a small applied magnetic field results in a large phase shift. More specifically, the value of magnetic field necessary for a given phase shift is reduced by approximately the Q of the cavity. Although such high order mode cavities have Q's typically of 10,000 to 30,000 and even higher, the presence of the ferrite reduces this considerably. Consequently, the loaded cavity Q is of the order of 100 to 1000, which represents a like factor in the reduction of magnetic field strength necessary for a given phase shift.

As previously noted, the flux density gradient of the applied field causes the above mentioned phase shift to be tapered in like manner across the cavity. As a result, the energy emerging from the output coupling holes **31** of the cavity has a phase front which is deflected from the original direction of propagation in the azimuth plane. Different phase front deflections of the emerging millimeter wave energy can be selected by varying the flux density gradient across the cavity. By using electromagnets **14** and **16** (FIG. 2) about cavity **18** (FIG. 3), this field gradient variation can be readily accomplished by appropriately varying the respective control currents applied to the electromagnets. Continuous scanning of a desired sector at a given rate may be accomplished by using electromagnet control currents having appropriate periodic waveforms of desired amplitude and frequency.

Referring now to FIGS. 4 and 5, a preferred embodiment of the invention is shown which is capable of providing two dimensional scanning. This antenna includes a cavity **32** which is quite similar to cavity **18** (FIG. 3) in that it is filled with a ferrite material **34**, in the form of cubes, and has a pair of parallel sides **32***a* and **32***b*, with side **32***a* containing an array of input coupling holes **36** and **32***b* containing an array of output coupling holes **38**. The cavity is energized by a radiating horn **40** fed by a waveguide **42**, which is excited in a TE mode with an E-vector in the direction indicated in FIG. 5. The excitation means is not shown in FIGS. 4 and 5, but it may be the same as that described with respect to FIG. 3. In this instance, however, a half wave plate **44** is disposed in the cavity parallel with and midway between sides **32***a* and **32***b*, thereby partitioning the cavity into two sections. The cavity section between input coupling side **32***a* and the half wave plate is denoted as **32***x*, and the cavity section adjacent to the output coupling holes **38** is denoted as **32***y*.

Tuning apparatus is not shown in the drawings, however, any of the conventional methods may be employed to tune cavity **32** to resonance at the frequency of the applied millimeter wave energy.

A half wave plate has the well known property of rotating a linearly polarized wave by 90° and may be implemented in any of a wide variety of forms. A design technique preferred in a present application is to employ a rectangular sheet of dielectric material having a set of copper gratings etched on it in the manner of a printed circuit board. The gratings are designed to act as shunt susceptances for producing the desired 90° rotation of an incident linearly polarized wave. Use of the half plate partition **44** in the present invention, therefore, produces a 90° rotation of the E field vector of the TE mode (linearly polarized) energy propagating through cavity **32**. As a consequence, the E-vectors of the energy in cavity sections **32***x* and **32***y* are respectively orthogonal, as illustrated in FIG. 5.

Two dimensional scanning is achieved by respectively applying orthoional magnetic fields to the partitioned cavity sections in directions parallel with the respective E field vectors in each section, as indicated in FIG. 5. More specifically, cavity section **32***x* is subjected to a magnetic field which is applied in the same direction as the E field vector of the wave energy propagating through that particular section. Since half wave plate **44** rotates the E field vector by 90°; however, section **32***y* is subjected to a magnetic field which is orthogonal to the field applied to section **32***x* and parallel to the direction of the E field vector of the energy traversing cavity section **32***y*. Consequently, each of these applied magnetic fields is operative to affect the permeability of the ferrite contained in the cavity section to which it is applied to thereby cause a phase shift in the energy traversing that section. As noted in the earlier discussion of pertinent physical properties, however, the electromagnetic wave will interact with the ferrite only when the circularly polarized magnetic (H) field of the wave traversing the ferrite has the same sense of rotation as the electron gyroscope caused by the static magnetic field in the ferrite. Hence, permeability, and thus phase shift, can be varied in the present case only when the magnetic field is applied in the same direction as the E field vector. The adavntageous consequence is that cross-talk between scan directions is eliminated, since the field applied to cavity section **32***x* will affect only section **32***x* and have no affect on the orthognally polarized energy in section **32***y*, and the field applied to section **32***y* will affect only that section and not section **32***x*.

In order to provide the desired phase front deflections of the millimeter wave energy, each of the magnetic fields also has a flux density gradient across the cavity section to which it is applied so as to cause the phase shift to be tapered across that section. Variation of the flux density gradient of the field applied to cavity section **32***x* scans the wave energy in the azimuth plane, while variation of the field gradient across section **32***y* adds to this an elevation scanning effect. As a result, the wave energy emerging from cavity **32** via output coupling holes **38** will have a phase front at an angle α to the original direction of propagation, with α being the resultant of the azimuth and elevation scan angles.

Each of the orthogonal magnetic fields can be provided in the same manner described for FIGS. 1–3. An arrangement of electromagnets about cavity section **32***x* as shown in FIG. 2 will control azimuth scanning, while an arrangement of electromagnets about section **32***y* as shown in FIG. 6 will produce elevation scanning. For application to FIGS. 4 and 5, FIG. 2 represents, a diagrammatic view of the output side of cavity section **32***x*, and FIG. 6 is a diagrammatic view of the output end of cavity section **32***y*. The tapered magnetic field, or flux density gradient, is illustrated in FIG. 2 by the arrows of increasing length from left to right across ferrite body **10** (which, as applied to FIGS. 4 and 5, represents the ferrite in section **32***x*) and in FIG. 6 by the arrows of increasing length from top to bottom across the ferrite **34** in section **32***y*. FIG. 6 shows electromagnets **46** and **48** arranged to subject cavity **32***y* to a magnetic field which is parallel to the direction of the E field vector of the energy traversing it. The electromagnets are also arranged to provide the desired flux density gradient across section **32***y* upon appropriate application of a variable control current to the respective input terminals **46***a*, **46***b*, and **48***a* and **48***b*.

In summary, the present invention provides beam scanning of linearly polarized millimeter wave energy by using a ferrite filled resonant cavity in a tapered magnetic field. Two dimensional antenna beam scanning is provided by the use of a ferrite filled resonant cavity having a half

wave plate located midway in the cavity so as to rotate the E-vector by 90° and having orthogonal magnetic fields applied thereto. Because of the multiple passes of the wave energy through the cavity, high efficiency scanning is achieved since a proportionately smaller field is required to achieve a given phase shift. This reduction in the magnetic field strength required, in turn, permits the use of larger apertures with attendant narrow beamwidths. Further, the wave energy is completely contained until emergence from the output coupling holes of the cavity, and there is no cross-talk between scan directions, since the orthogonal magnetic fields produce no effect on the undesired polarization.

Although there has been described what are now considered to be preferred embodiments of the invention, modifications falling within the scope and spirit of the invention will occur to those skilled in the art. For example, other ferrimagnetic materials than ferrite may be employed. Means other than a radiating horn may be used to feed the cavity, such as a rectangular waveguide with one or more coupling holes in the input side of the cavity. As suggested in the Culshaw references, the cavity input and output coupling means may comprise stacked dielectric plates, or stacked planar or rod gratings. Further, instead of being parallel plate reflectors, the cavity sidewalls may be curved to provide a focused resonator. It is the intention of the applicant, therefore, that the invention is not to be limited by what has been specifically illustrated and described, except as such limitations appear in the appended claims.

What is claimed is:

1. An electromagnetic wave scanner comprising, a resonant cavity filled with ferrimagnetic material and having energy input and output coupling means, waveguide means adapted to be connected to a source of electromagnetic wave energy and arranged to direct said energy into said cavity through the input coupling means thereof, means for subjecting said cavity to a magnetic field having a flux density gradient across said cavity, said magnetic field being operative to affect the permeability of the ferrimagnetic material in said cavity to thereby cause a phase shift in energy traversing said cavity, the flux density gradient of said field causing said phase shift to be tapered across said cavity, and means for varying the flux density gradient of said magnetic field for enabling selective phase front deflection of electromagnetic wave energy emerging from the output coupling means of said cavity.

2. A scanner in accordance with claim **1** wherein said waveguide means is adapted to be excited in a TE mode, and said magnetic field is applied in the same direction as the electric field vector of the TE mode energy propagating through said cavity.

3. A scanner in accordance with claim **2** wherein the output coupling means of said cavity comprises an array of regularly spaced coupling holes in a first side of said cavity.

4. A scanner in accordance with claim **3** wherein said waveguide means comprises a radiating horn, and said input coupling means comprises an array of regularly spaced coupling holes in a second side of said cavity, said second side being opposite the first side of said cavity and said horn being arranged with its mouth facing the second side of said cavity.

5. A scanner in accordance with claim **4** wherein the ferrimagnetic material filling said cavity is a ferrite.

6. A scanner in accordance with claim **5** wherein the first and second sides of said cavity are parallel plates of a material capable of reflecting electromagnetic energy traversing said cavity.

7. An electromagnetic wave scanner comprising, a resonant cavity filled with ferrimagnetic material and having energy input and output coupling means, a half wave plate disposed in said cavity between the energy input and output coupling means whereby said cavity is partitioned into first and second sections, waveguide means adapted to be connected to a source of electromagnetic wave energy and arranged to direct said energy into said cavity through the input coupling means thereof, means for subjecting the first section of said cavity to a magnetic field having a flux density gradient across said first section, means for subjecting the second section of said cavity to a magnetic field orthogonal to the field applied to the first section and having a flux density gradient across said second section, each of said magnetic fields being operative to affect the permeability of the ferrimagnetic material in the cavity section to which it is applied to thereby cause a phase shift in energy traversing that cavity section, the flux density gradient of each of said fields causing said phase shift to be tapered across the cavity section to which it is applied, and means for varying the flux density gradients of said magnetic fields for enabling two dimensional scanning of electromagnetic wave energy emerging from the output coupling means of said cavity.

8. A scanner in accordance with claim **7** wherein said waveguide means is adapted to be excited in a TE mode, and each of said magnetic fields is applied in the same direction as the electric field vector of the TE mode energy propagating through the cavity section to which it is applied, said half wave plate being operative to rotate by 90° the electric field vector of TE mode energy propagating through said cavity.

9. A scanner in accordance with claim **8** wherein the output coupling means of said cavity comprises an array of regularly spaced coupling holes in a first side of said cavity.

10. A scanner in accordance with claim **9** wherein said waveguide means comprises a radiating horn, and said input coupling means comprises an array of regularly spaced coupling holes in a second side of said cavity, said second side being opposite the first side of said cavity and said horn being arranged with its mouth facing the second side of said cavity.

11. A scanner in accordance with claim **10** wherein the ferrimagnetic material filling said cavity is a ferrite.

12. A scanner in accordance with claim **11** wherein the first and second sides of said cavity are parallel plates of a material capable of reflecting electromagnetic energy traversing said cavity, and said half wave plate is disposed parallel with and midway between the first and second sides of said cavity.

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