United States Patent [19]

Charlot, Jr.

[11] **3,803,623**

[45] **Apr. 9, 1974**

[54] **MICROSTRIP ANTENNA**

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[22] Filed: **Oct. 11, 1972**

[21] Appl. No.: **296,592**

[52] **U.S. Cl.** .... **343/846,** 343/769, 343/853, 333/84 M

[51] **Int. Cl.** **H01q 1/48,** Ho1p 3/08

[58] **Field of Search** .... 343/769, 846, 705, 708, 343/853; 333/84 M

[56] **References Cited**

UNITED STATES PATENTS

3,478,362	11/1969	Ricardi et al.	343/769
3,665,480	5/1972	Fassett	343/769

FOREIGN PATENTS OR APPLICATIONS

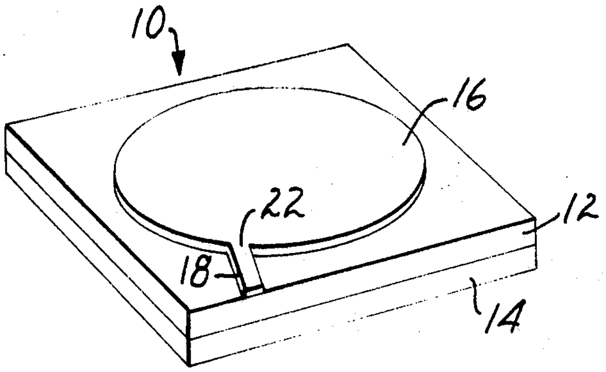
1,050,583	9/1953	France	343/705

Primary Examiner—Eli Lieberman
Attorney, Agent, or Firm—Alexander, Sell, Steldt & DeLaHunt

[57] **ABSTRACT**

Microstrip antenna having a single radiator element or an array of radiator elements. The radiator elements are elliptical with the minor axis in the E plane being approximately $\lambda(2\sqrt{\mu_r\epsilon_r})$. The radiator elements and feed elements are contained in a broad surface which is uniformly spaced from a ground element by a dielectric layer, and are impedance matched to a transmission line by selecting a feedpoint on the periphery of the radiator element at which the input impedance of the radiator element effects an impedance match to the transmission line.

24 Claims, 7 Drawing Figures



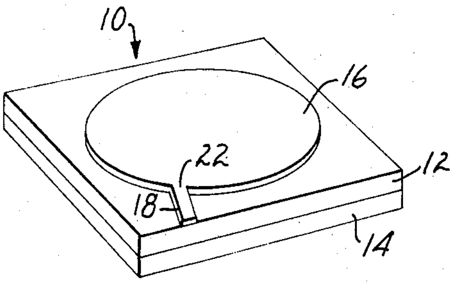


FIG. 1

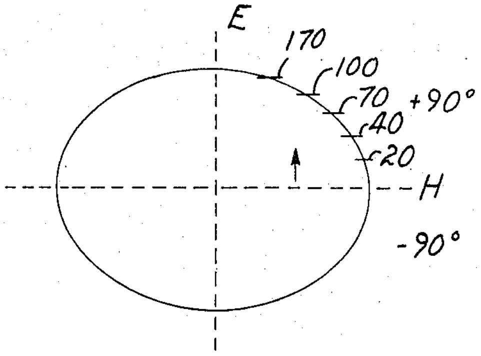


FIG. 2

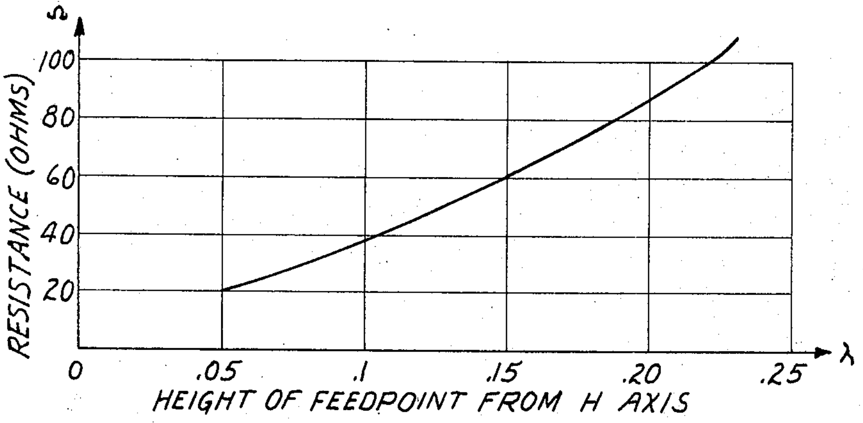


FIG. 3

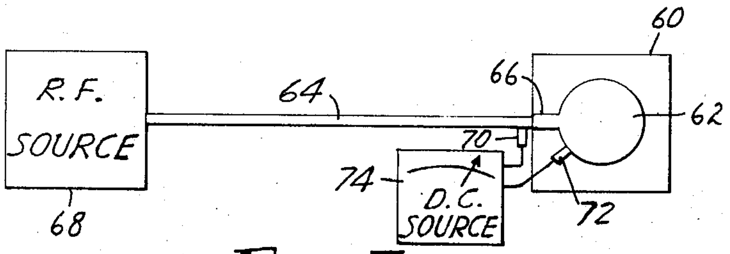


FIG. 7

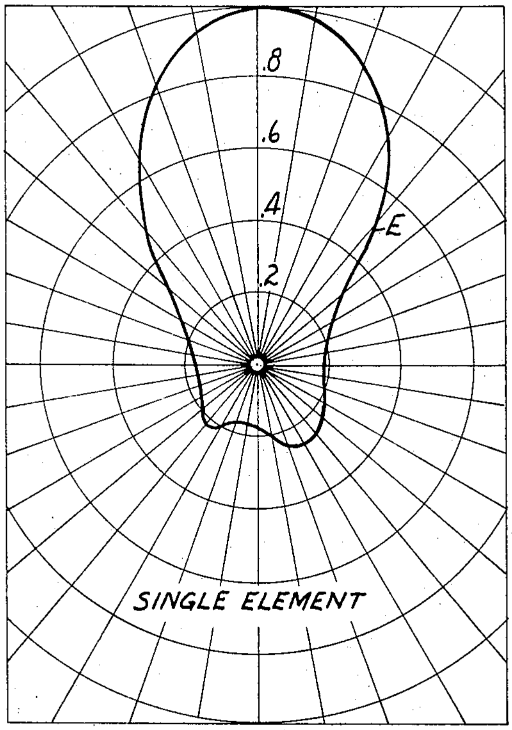


FIG. 4

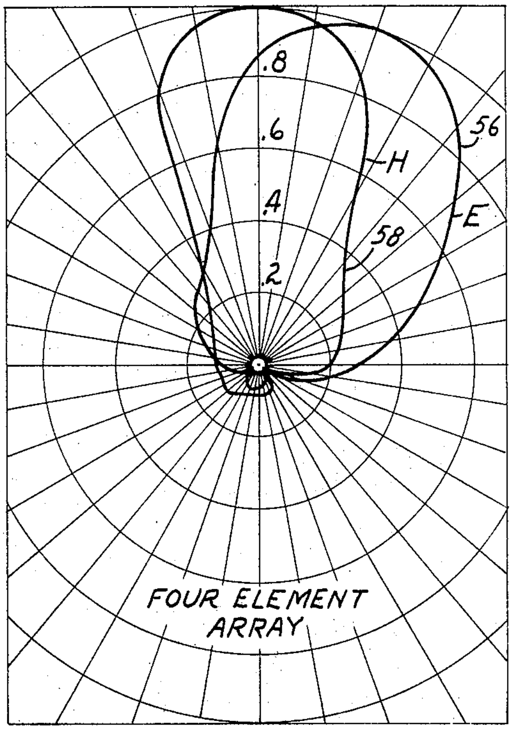


FIG. 6

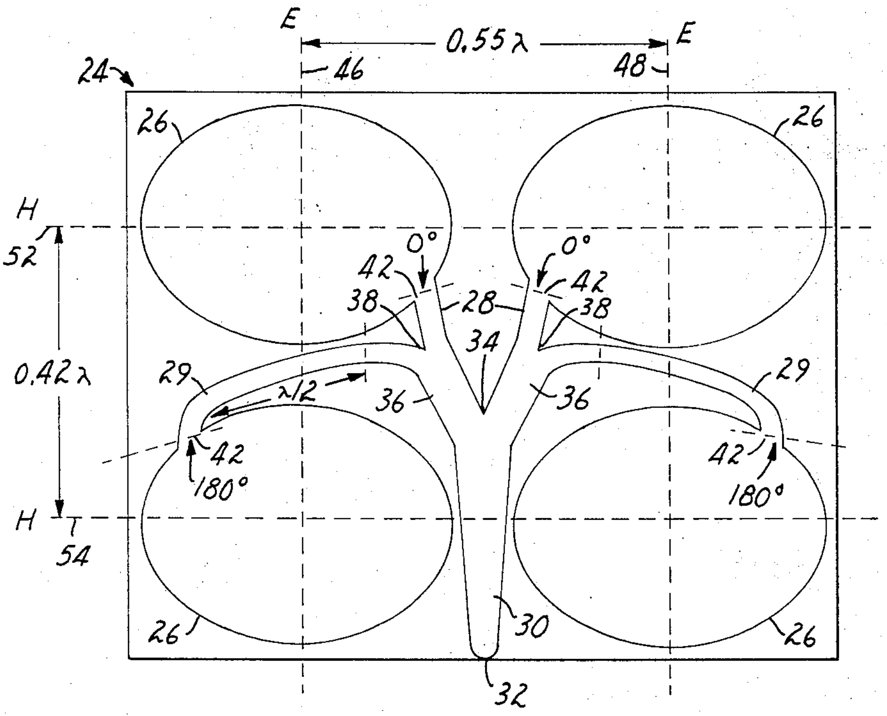


FIG. 5

MICROSTRIP ANTENNA

BACKGROUND OF THE INVENTION

There is a growing need to provide a low cost, compact, low profile, and readily mass-producible, high-aperture-efficiency antenna of useful bandwidth in which the raidator elements can be readily matched to a range of useful transmission line impedances for radiating or receiving a directional, linearly polarized, electromagnetic radiation beam. Such an antenna would be especially useful for low cost object sensing and microwave communications.

The desirable characteristics of low profile, of high aperture efficiency and of a highly directional linear beam of useful bandwidth are provided by compact printed circuit stripline antennas, such as described by Jones in "Integrated Radome-Antenna Designs," Microwaves, September, 1967, wherein a conductor is spaced by two dielectric layers between two ground planes, one of which is slotted. However, such stripline antennas have severe registration and mode suppression requirements and are too complex for low cost applications.

Another low profile antenna is described in U.S. letters Pat. No. 3,680,136. However, this antenna is also of somewhat complex construction in that it requires electrical feed means at two points on the under surface of a circular or polygonal radiator element to define an axis of polarization and further requires a pair of tuning capacitors positioned at the edge of the radiator element between the radiator element and a ground element.

A simpler form of low profile antenna employs a printed circuit construction including a microstrip element. "Microstrip" is a term which is commonly applied to non-radiating circuit element such as microwave filters, couplers, tuning stubs and other elements comprising flat conductive strips which are spaced from a single continuous ground plane element by a dielectric layer.

One type of compact readily mass-producible antenna having a microstrip configuration is described in U.S. letters Pat. No. 3,016,536 wherein rectangular radiator elements are distributed in an array over a broad surface and the major axis of the rectangle approximates $\lambda/(2\sqrt{\mu_r\epsilon_r})$. ϵ_r and μ_r are respectively the dielectric constant and permeability of the dielectric layer. However, the rectangular radiating element antenna disclosed in the cited patent requires a balanced drive, has a poor aperture efficiency and a narrow bandwidth, and requires a dielectric thickness of about one quarter wavelength, in that it is designed to use the ground plane element as a relector whereby the dielectric layer thickness is a function of the wavelength of the propagated radiation.

Studies of microstrip elements have indicated that in common configurations they possess the properties of low radiation and low attenuation. Microstrip elements are generally known to be poor radiators of electromagnetic energy. For example, the theoretical studies concerning elliptical microstrip elements reported by Irish in "Electronics Letters" Apr. 8th 1971, Vol. 7, No. 7, page 149; and by Kretzschmar in "IEEE Transactions on Microwave Theory and Techniques," May, 1972, page 342, indicate that although such an element would resonate efficiently at a wavelength for which either ellipse axis approximates $\lambda/(2\sqrt{\mu_r\epsilon_r})$, or in a number of other modes, the Q factor of such element would be on the order of 1,000 or higher, thereby precluding efficient radiation.

Tests with common rectangular microstrip elements supported by a thin low-loss dielectric layer and having a strip width on the order of, or less than $\lambda/4$, demonstrate unloaded Q factors of several hundred, and loaded Q factors on the order of 100 or more. These high Q factors indicate a radiation resistance which is too high for most antenna applications.

SUMMARY OF THE INVENTION

I have learned how to convert a microstrip element into an efficient radiator of electromagnetic radiation. In order to realize efficient radiation, it is critical that the feed element be coupled to the microstrip element at the correct position. When so coupled, the microstrip element provides an antenna of high aperture efficiency and useful bandwidth which is readily mass-producible at low cost.

An antenna according to the present invention, which is constructed to be impedance matched to a transmission line of an input impedance Z at a wavelength λ for radiating or detecting electromagnetic radiation signals having the wavlength λ, includes

a thin conductive radiator element having a broad surface and two unequal orthogonal axes of symmetry in the broad surface for defining E and H planes, which planes respectively include said axes;

a conductive ground element uniformly spaced from and more than coextensive with the radiator element for defining a radiator aperture; and

a dielectric layer of relative dielectric constant ϵ_r and relative permeability μ_r and of uniform thickness for spacing the radiator element from the ground element.

In order to achieve high radiation efficiency a single electrical feed element is coupled to the radiator element at an off-axis feedpoint on the latter selected for impedance matching the radiator and feed elements to the transmission line. Also the axis which is within the E plane should be approximately $\lambda/(2\sqrt{\mu_r\epsilon_r})$. A broader bandwidth is provided when the minor axis is in the E plane.

Selection of the feedpoint on the radiator element is facilitated by the feature that the input impedance of the radiator element is dependent upon the position of the feedpoint on the periphery of the radiator element. This input impedance is approximately zero at the axis which lies in the H plane and increases along the periphery, becoming maximum at the axis which lies in the E plane. The feedpoint-input impedance relationship is symmetrical in the quadrants on either side of the E plane and in the quadrants on either side of the H plane, except that the relative phase of the radiated signal reverses by 180° as the feedpoint crosses the H plane. This feature makes it relatively easy to impedance match the radiator element and the electrical feed element to the transmission line, since one need only select a feedpoint on the radiator element periphery which provides the desired input impedance at the wavelength of the electromagnetic radiation to be radiated or received. Also, except when the radiator element is a circle, the orientation of the plane of polarization is relatively independent of the position of the feedpoint.

The embodiment of the antenna wherein the radiator element is circular has certain unique properties. Because the polarization plane of the circular radiator element antenna is dependent upon the combination of the feedpoint and the transmission line characteristics, and not dependent upon the physical placement of major and minor axes, the polarization plane can be predetermined by merely adjusting the electrical characteristics of the impedance match to the transmission line. Thus the plane of polarization can be varied for scanning or searching functions by electronically varying the reactive characteristics of the impedance match to the transmission line.

The preferred shape of the radiator element is that of an ellipse, although rectangles or other orthogonally symmetrical configurations may also be used. I found that the best combination of high aperture efficiency and useful bandwidth are realized with an ellipse having an eccentricity of about 0.65. The upper practical limit of eccentricity appears to be about 0.9.

For the preferred radiator element shape of an ellipse, an excellent impedance match can thus be made to transmission lines having an input impedance in a range of from 20 to 150 ohms.

The following effects of varying the eccentricity have been observed. As the eccentricity increases above about 0.4 the frequencies of the two lowest resonant modes which occur for the two possible orientations of the E field along the major and minor axes become further apart, thereby resulting in better decoupling of the lowest mode from the desired mode in which the E plane includes the minor axis. However, as the eccentricity increases above about 0.8 there is an increasing likelihood of coupling of energy into an unwanted still higher resonant mode. With the dimension of the radiator element along the minor axis (E plane) held constant, increasing the major axis dimension results in only a slight increase in the operating frequency. However, with the major axis dimension held constant, increasing the minor axis dimension causes the operating wavelength to proportionately increase within the limits of eccentricity.

For microstrip antennas constructed according to the present invention, the unloaded Q factor, as measured with a network analyzer was observed to be less than 75, and the loaded Q factor less than 25. For the preferred elliptical radiator element embodiment, wherein the eccentricity is 0.65, the unloaded Q factor was observed to be less than 25, and the loaded Q factor less than 12, thereby resulting in a usable half-power bandwidth of about 2%. For elliptical radiator element antennas having an eccentricity of 0.65 a gain of about 6 db was measured for a single element antenna, and a gain of about 11 db was measured for a four element array antenna. The radiation efficiency was determined to be greater than 95% of theoretical efficiency.

In the antennas of the present invention, the spacing of the radiator element from the ground element is not a function of the wavelength of the electromagnetic radiation. Thus extremely low profile antennas may be provided, wherein the thickness of the dielectric layer for uniformly spacing the radiator element from the ground element is extremely thin. A thickness in a range between about $\lambda/(20\sqrt{\mu_r\epsilon_r})$ and $\lambda/(50\sqrt{\mu_r\epsilon_r})$ is preferred. Within this range a greater bandwidth is obtained with thicker substrates.

In view of the foregoing features constructions of high gain arrays are easily achieved by etching the radiator and feed elements from one side of high quality double clad circuit boards of the desired design thickness. To produce high gain antennas an array of radiator elements is appropriately distributed on a broad surface of the circuit board. By suitably selecting the impedances and lengths of the feed elements which interconnect the array of radiator elements to the transmission line, and by suitably selecting the quadrants and locations of the raidator element feedpoints, power may be distributed to a plurality of radiator elements in accordance with the desired illumination function, wherein the side lobes may be controlled. Thus the radiator elements may be properly phased and individually impedance matched to the feed elements and to the transmission line. For a large more or less square array of radiator elements, the radiated or received radiation beam is a pencil beam which is highly directional in both the E and H planes.

Linear arrays may also be constructed to produce fan beams which are highly directional in a plane which includes a line joining the radiator elements, which plane may be either and E or an H plane depending upon the orientation of the elliptical radiator elements.

Because the individual radiator elements are themselves directional the fields in the plane of the array near the radiator elements are low, thereby allowing the transmission line and the connector element lines to be routed close to the radiator elements. Also when adjacent radiator elements are placed close together, the usual problems of mutual field coupling are not as great.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a perspective view of an antenna according to the present invention, having a single radiator element.

FIG. **2** shows approximate values of input impedance of an elliptical radiator element at various feedpoints on the periphery thereof.

FIG. **3** is a graph showing the value of the resistance component of the input impedance of the radiator element of FIG. **2**, as a function of the height of the feedpoint from the H axis.

FIG. **4** is a graph of a measured radiation pattern for the antenna of FIG. **1**.

FIG. **5** is a plan view of a multiple element array antenna according to the present invention.

FIG. **6** is a graph of measured gain and radiation patterns for the antenna of FIG. **5**.

FIG. **7** is a schematic representation of a system employing an antenna having a circular radiator element for scanning or search applications.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A single radiator element embodiment of the antenna of the present invention is shown in FIG. **1**, wherein the thicknesses of the copper clad radiator, ground and feed elements are exaggerated. The antenna **10** includes a dielectric layer **12**, which uniformly separates a ground element **14** from a radiator element **16** and an electrical feed element **18**. The radiator element **16** is an ellipse having an eccentricity of 0.65. The feed element **18** is illustrated as being directly connected to the radiator element **16**, at a feedpoint **22** but it may be capacitively coupled thereto. Also the feed elements **18** may be connected to a transmission line by quarter wave transformers or other impedance transitions.

The antenna **10** is made from a double copper clad low-loss printed circuit board material by etching one layer to form the radiator element **16** and the feed element **18.**

The feedpoint **22** was selected to match a transmission line characteristic impedance of 50 ohms to a radiator element input impedance of 50 ohms. the impedance of the feed element **18,** as determined by its width, is also 50 ohms.

The dielectric layer **12** is polytetrafluoroethylene (PTFE), which has a relative dielectric constant ϵ_r of about 2.5, and a relative permeability μ_r of 1.0. The copper layers are about 35 micrometers thick, and the dielectric layer has a thickness of about 1.5 millimeters.

FIG. **2** shows approximate values of radiator element input impedance, in ohms, at various feedpoints on the periphery on the elliptical radiator element, as empirically determined for the embodiment described above, when designed to radiate at approximately 2.6 GHz, with the E field parallel to the minor axis.

FIG. **3** is a graph showing the value of the resistance component of the radiator element input impedance in ohms as a function of the height of the feedpoint from the H axis in terms of wavelength λ. FIG. **3** is applicable for only the above described embodiment.

The gain for this antenna **10** was measured at +5.95 db over isotropic. This measurement was made by using the commonly used two antenna technique. This measured gain is about 95% of the theoretical gain. The gain and radiation pattern for the antenna **10,** as designed in accordance with the teaching of the present invention for radiating a 2.6 GHz signal, is shown in FIG. **4.** Measurements were made in the E plane.

A multiple element array antenna **24** is shown in FIG. **5.** The antenna **24** is made from the same materials as used in the single element antenna **10** described above. The antenna **24** has four radiator elements **26** which are individually coupled to interconnected feed elements **28** and **29.** The feed elements **28** and **29** branch out from a trunk feed element **30** which is connected to the transmission line. The trunk feed element **30** is tapered so as to change its impedance from 50 ohms at the terminal **32** for connection to the transmission line, to 25 ohms at the junction **34** where it divides to form the branch elements **36.** The branch feed elements **36** are each tapered so as to change their respective impedances from 50 ohms at the junction **34** to 35 ohms at the junction **38** where it divides to form the feed elements **28** and **29.** The feed elements **28** and **29** are each 70 ohms, and the feedpoints **42** on the radiator elements **26** are selected to match a radiator element input impedance of 70 ohms.

The feedpoints may be at any of four different points on the periphery of the radiator elements **26** for any given selected input impedance. The 180° phase difference which exists for feedpoints on either side of the major ellipse axis enables groupings of two or four radiator elements **26** to be fed from a single trunk feed element **30** with the difference in the lengths between the lines **28** and **29** being only λ/2 rather than a full wavelength λ. In the four element array of this embodiment an estimated loss of approximately 0.5 db was saved by using this technique.

FIG. **5** is drawn to scale. The E planes **46** and **48** are separated by 0.55 λ and H planes **52** and **54** are separated by 0.42 λ.

The gain for the four element array antenna **24** was found to be about 11 db, which is approximately equal to the theoretical gain, as based on the antenna aperture corresponding to the area of the ground plane. The gain and radiation patterns **56** and **58,** respectively measured in the E and H planes, are shown in the polar graph of FIG. **6.** The frequency of the radiated signal was 2.57 GHz. The voltage standing wave ratio (VSWR) was observed to be 1.5 to 1.

A 26 db gain array involves the use of the same design techniques described above. The major problems are related to the physical size of the array and the need to control phase and power distribution across the array. In most applications the array will generate pencil beams or flat fan beams both of which will often require binomial or other power distribution to eliminate high side lobes. With a planar array of elliptical radiator elements, accurate control of this power distribution is readily achievable because of the design flexibility in choosing the feed points, phase and load impedance. Approximately 128 elements are required for a 26 db gain uniformly illuminated square array 9 × 9 wavelengths in size. This figure of **128** is an estimate based on the 11 db achieved for the **4** element array and further based on the assumption that an additional 3 db is obtained each time the array is doubled in size and that near theoretical efficiency is not sacrificed by the additional line loss, mismatch loss and phasing error. For arrays this size, the greatest design difficulty will be in eliminating phase errors and in reducing sidelobe content, especially for designs in monopulse applications.

FIG. 7 shows an embodiment wherein an antenna **60** has a circular radiator element **62** connected to a transmission line **64** by a feed element **66.** The transmission line **64** is connected to a radio frequency signal source **68.** Variable reactance elements, such as varactors **70** and **72,** are respectively connected between the transmission line **64** and an electrical ground, and between the radiator element **62** and ground. Both varactors **70,72** are connected to a variable D.C. source **74.** By varying the D.C. voltage to the varactors **70,72** the plane of polarization of the antenna **60** is likewise varied, thereby enabling the antenna to be used for scanning or search applications.

What is claimed is:

1. A microstrip antenna which is impedance matched to a transmission line of an impedance Z at a wavelength λ for radiating or detecting electromagnetic radiation signals having the wavelength λ, comprising

a thin conductive radiator element having a broad surface and two unequal orthogonal axes of symmetry in the broad surface for defining E and H planes which planes respectively include said axes, with the axis within the E plane being approximately $\lambda/(2\sqrt{\mu_r\epsilon_r})$;

a conductive ground element uniformly spaced from and more than coextensive with the radiator element for defining a radiator aperture;

a dielectric layer of relative dielectric constant ϵ_r and relative permeability μ_r and of uniform thickness for spacing the radiator element from the ground element; and a single electrical feed element for connection to the transmission line and coupled to a peripheral portion of the radiator element at a feedpoint which is off of said axes.

2. An antenna according to claim **1**, with the minor axis being in the E plane.

3. An antenna according to claim **1**, wherein the radiator element is an ellipse having an eccentricity greater than zero.

4. An antenna according to claim **3**, wherein the eccentricity is between 0.4 and 0.9.

5. An antenna according to claim **4**, wherein the eccentricity is 0.65.

6. An antenna according to claim **4**, wherein the radiator element has a minor elliptical axis in the E plane.

7. An antenna according to claim **6**, wherein the eccentricity is 0.65.

8. An antenna according to claim **1**, wherein the feed element has a broad surface uniformly spaced from the ground element by the dielectric layer.

9. An antenna according to claim **1**, wherein the feed element has a broad surface uniformly spaced from the ground element by the dielectric layer.

10. A microstrip antenna which is impedance matched to a transmission line of an impedance Z at a wavelength λ for radiating or detecting electromagnetic radiation signals having the wavelength λ, comprising

a thin circular conductive radiator element having a broad surface and a diameter of approximately $\lambda/(2\sqrt{\mu_r\epsilon_r})$;

a conductive ground element uniformly spaced from and more than coextensive with the radiator element for defining a radiator aperture;

a dielectric layer of relative dielectric constant ϵ_r and relative permeability μ_r and of uniform thickness for spacing the radiator element from the ground element;

an electrical feed element for connection to the transmission line and coupled to the radiator element at a feedpoint selected for impedance matching the radiator and feed elements to the transmission line; and

variable reactance elements coupled to the radiator element and the transmission line for enabling a plane of polarization of the antenna to be varied by varying the reactance of the variable reactance elements.

11. A microstrip antenna which is impedance matched to a transmission line of an impedance Z at a wavelength λ for radiating or detecting electromagnetic radiation signals having the wavelength λ, comprising

an array of thin conductive radiator elements distributed on a broad surface, said radiator elements individually having two unequal orthogonal axes of symmetry in the broad surface for defining E and H planes which planes respectively include said axes with the axis within the E plane being approximately $\lambda/(2\sqrt{\mu_r\epsilon_r})$;

a conductive ground element uniformly spaced from and more than coextensive with the radiator elements for defining a radiator aperture;

a dielectric layer of relative dielectric constant ϵ_r and relative permeability μ_r and of uniform thickness for spacing the radiator elements from the ground element; and

electrical feed elements for connection to the transmission line and individually coupled to each radiator element at feedpoints wherein each radiator element has a single said feed element, at least some of which are coupled to the radiator elements at feedpoints off of said axes.

12. An antenna according to claim **11**, with the minor axes of the individual radiator elements being in the E plane.

13. An antenna according to claim **11**, wherein the individual radiator elements are ellipses having an eccentricity greater than zero.

14. An antenna according to claim **13**, wherein the eccentricity is between 0.4 and 0.9.

15. An antenna according to claim **14**, wherein the eccentricity is 0.65.

16. An antenna according to claim **14**, wherein the individual radiator elements have a minor elliptical axis in the E plane.

17. An antenna according to claim **16**, wherein the eccentricity is 0.65.

18. An antenna according to claim **16**, wherein the feed elements are coupled to the peripheries of the radiator elements.

19. An antenna according to claim **11**, wherein the feed elements are coupled to the peripheries of the radiator elements.

20. An antenna according to claim **19**, wherein the individual feed elements each have a broad surface uniformly spaced from the ground element by the dielectric layer.

21. An antenna according to claim **11**, wherein the feed elements each have a broad surface uniformly spaced from the ground element by the dielectric layer.

22. A microstrip antenna which is impedance matched to a transmission line of an impedance Z at a wavelength λ for radiating or detecting electromagnetic radiation signals having the wavelength λ, comprising

an array of thin circular conductive radiator elements distributed on a borad surface, said radiator elements individually having a diameter in the broad surface of approximately $\lambda/(2\sqrt{\mu_r\epsilon_r})$;

a conductive ground element uniformly spaced from and more than coextensive with the radiator elements for defining a radiator aperture;

a dielectric layer of relative dielectric constant ϵ_r and relative permeability μ_r and of uniform thickness for spacing the radiator elements from the ground element; and

electrical feed elements interconnected to one another for connection to the transmission line and individually coupled to each radiator element at feed points selected for impedance matching the radiator and feed elements to the transmission line; and

variable reactance elements coupled to the radiator elements and the transmission line for enabling a plane of polarization of the antenna to be varied by varying the reactance of the variable reactance elements.

23. An antenna according to claim **1**, wherein the position of the feedpoint on the radiator element is selected so that the impedance of the radiator element at the feedpoint is equal to the impedance of the feed element at said feedpoint.

24. An antenna according to claim **11,** wherein the positions of the feedpoints on the radiator elements are selected so that the impedance of each radiator element at its feedpoint is equal to the impedance of the feed element at said feedpoint.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,803,623 **Dated** April 9, 1974

Inventor(s) Lincoln H. Charlot

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Abstract

At line 4, change " $\lambda(2\sqrt{\mu_r\varepsilon_r})$" to -- $\lambda/(2\sqrt{\mu_r\varepsilon_r})$ --.

In the Patent

Column 1, line 8, change "raidator" to -- radiator --.

Signed and sealed this 1st day of October 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents