ANNULAR SLOT ANTENNA WITH STRIPLINE FEED

Inventor: Matthew Fassett, Billerica, Mass.
Filed: Jan. 23, 1969
Appl. No.: 793,266

U.S. Cl. 343/754, 343/768, 343/769, 343/854
Int. Cl. H01q 3/26
Field of Search 343/767, 343/769, 770, 771, 343/854, 754; 333/84 M

References Cited
UNITED STATES PATENTS
2,637,814 5/1953 Johnson 343/769
2,654,842 10/1953 Engelmann 343/770
2,977,595 3/1961 Ziser et al. 343/769
3,086,204 4/1963 Alford 343/769
3,165,743 1/1965 Hatkin 343/767
3,354,461 11/1967 Kelleher 343/754

Primary Examiner—Eli Lieberman
Attorney—Harold A. Murphy and Joseph D. Pannone

ABSTRACT
A stripline antenna having a radiating aperture in the form of an annular slot provided in one of its conducting plates and a pair of orthogonal narrow strip conductor feeds disposed between its two conducting plates and terminating under the central disk formed by the annular slot. Adjustment of the relative phase and amplitude of the electromagnetic energy applied to the strip conductor feeds permits radiation from the annular slot of circular, elliptical or orthogonal linear polarizations into space or into a waveguide.

15 Claims, 14 Drawing Figures
ANNULAR SLOT ANTENNA WITH STRIPLINE FEED

BACKGROUND OF THE INVENTION

This invention relates to stripline and microstrip antennas and more particularly to an annular slot type of stripline antenna employing orthogonal feed structures. In many applications, small lightweight antenna elements are desirable, such as for use in phased array antenna applications, and particularly aircraft and missile antennas, as well as for use in coupling electromagnetic radiation into waveguides. These antenna elements are preferably in the form of stripline or microstrip antenna elements which are readily fabricated to have a suitably small lightweight structure. It is also preferable that these antenna elements have an electrical structure which permits polarization of their electromagnetic radiation at any polarization angle so that the antenna can be used, for example, to excite within a waveguide mode of radiation which are coupled to the antenna aperture.

Stripline antennas formerly have frequently employed configurations of slot radiators and conducting strip radiators which have a capability for producing radiation having, typically, a fixed polarization rather than a capability for providing desirable polarization diversity. Other conventional forms of stripline and microstrip antennas have a crossed slot radiating aperture which provides a measure of polarization diversity capability. In this crossed slot form, the radiation emitted from one slot is polarized perpendicular to the radiation emitted from the other slot, the amplitude of each radiation being controllable so that radiation from the two slots combine to form a resultant radiation having the desired polarization. However, the crossed slot configuration introduces mutual coupling between the feed structures for each of the two crossed slots with a resultant decrease in the extent of polarization control.

Still other forms of stripline and microstrip antennas for use in polarization diversity applications avoid undesirable mutual coupling by having the two slots perpendicularly disposed in spaced apart relation, rather than as a crossed slot, so that the fields of radiation of the two slots are essentially decoupled from each other. However, the radiation from these two slots have separate phase centers which cause relative phase shifts between the fields radiated from the two slots in directions off the antenna axis while the phase centers are coincident in the case of the crossed slot antenna.

Accordingly, it is an object of the present invention to provide an improved stripline or microstrip-type antenna which provides radiation components having a common phase center and which permits varying the polarization of its radiation to provide a lightweight, readily fabricated antenna element of either the stripline or microstrip type which can serve as a coaxial-to-waveguide coupling device for exciting waveguide modes of differing polarizations.

SUMMARY OF THE INVENTION

In accordance with the invention, there is provided an antenna for radiating electromagnetic energy, the antenna comprising two substantially parallel electrically conducting plates supported in spaced-apart relationship by means of a dielectric support structure, a substantially annular slot radiating aperture provided in at least one of the conducting plates, and at least one stripline feed element having the form of an elongated electrical conducting strip embedded within the dielectric structure substantially equidistantly between and parallel with the conducting plates, and terminating at the annular slot. In the preferred embodiment, the annular slot circumference is approximately one wavelength of the free space radiation and there are provided two stripline feed elements which extend approximately one-tenth wavelength of the dielectric radiation under the central disk formed by the annular slot and have a circumferential spacing of substantially ninety degrees between the terminations which spacing corresponds to approximately one-quarter wavelength of the free space radiation. Accordingly, an electric field excited within the annular slot radiating aperture by one feed element has a null at the location of the termination of the other feed element to provide substantial electromagnetic decoupling between the two feed elements. Due to the ninety degree circumferential spacing of the feed elements, the radiation excited by one feed element has a polarization which is perpendicular to the polarization of the radiation excited by the other feed element. The direction of the resultant polarization of the sum of the two radiations is determined by the independently adjustable phases and amplitudes of electromagnetic signals applied to the two stripline feeds.

Alternative embodiments are disclosed showing a radiating aperture in each conducting plate; an antenna structure in which one conducting plate is deleted; and antennas having various forms of dielectric structures supporting the feed elements in relation to the conducting plates.

BRIEF DESCRIPTION OF THE DRAWINGS

The aforementioned objects and other features of the invention are explained in the following description taken in connection with the accompanying drawings, wherein:

FIG. 1 is a plan view, partially cut away, of one embodiment of the stripline antenna of the invention;
FIG. 2 is a sectional view of the embodiment of FIG. 1 taken along line 2—2;
FIG. 3 is a sectional view of another embodiment of the invention having an aperture disposed in each conducting plate;
FIG. 4 is the distribution of the electric field vector within an annular slot as provided by excitation from one feed element;
FIG. 5 is a further embodiment of the invention having a generally annular radiating aperture;
FIG. 6 is a partial plan view of an embodiment of the invention of FIG. 1 modified to utilize an alternative form of feed element having a perpendicularly projecting end tab;
FIG. 7 is a partial plan view of another embodiment of the invention showing a feed element which is shorted to a central disk formed by the annular slot in one conducting plate;
FIG. 8 is a sectional view of the embodiment shown in FIG. 7 taken along the line 8—8;
FIG. 9 is a sectional view of another embodiment of the invention utilizing an air dielectric and support structures formed by shorted quarter wavelength transmission lines;
FIG. 10 is an auxiliary view of the embodiment of FIG. 9 taken along the line 10—10;
FIG. 11 shows a method for exciting the feed elements whereby the phase of each feed element of the electromagnetic signal applied to one feed element can be varied with respect to the signal applied to the other feed element;
FIG. 12 shows in diagrammatic form the antenna of FIG. 1 in which individual phase shifters are connected to a pair of antennas of the invention so that radiation of a first polarization received on one feed element of each antenna is phase shifted prior to radiation at a second polarization;
FIG. 13 is an isometric view of the antenna of FIG. 1 affixed to the end of a waveguide for exciting modes of radiation in the waveguide; and
FIG. 14 shows in diagrammatic form a stripline antenna system for dissecting and reforming the radiation pattern of a horn radiator in which phase shifting elements are interconnected with three input and three output antennas of the form shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, there is shown respectively, a plan and sectional view of an embodiment of the invention in the form of a stripline antenna 18 comprising a front conducting plate 20 having a radiating aperture formed by an annular slot 22 and a back conducting plate 24 which is held in parallel relationship to the front plate 20 by means of a dielectric, polyphenylene oxide, though other materials can be used such
as well-known Teflon-fiberglass, composed of two layers, respectively 26A and 26B. Two feed elements in the form of longitudinal conducting strips, respectively 28 and 30, extend radially outward in perpendicular directions from approximately the perimeter of central disk 31 formed by the annular slot 22 and are embedded along the interface of the two dielectric layers 26A and 26B in parallel relationship to the plates 20 and 24 and spaced from these plates to support traveling electromagnetic waves by which electromagnetic energy is propagated to the annular slot 22 respectively from identical stripline to coaxial cable adapters 32 and 34.

The annular slot 22 has an inner circumference, namely the circumference of disk 31, which is slightly less than the free space wavelength of the highest frequency radiation which is radiated from the antenna. The outer circumference of the annular slot 22 has a circumference which is slightly longer than the free space wavelength of the lowest frequency radiation which is radiated from the antenna. In this embodiment the inner and outer radius of the slot 22 differ by approximately 20 per cent to provide approximately a 10 per cent bandwidth of the radiated frequencies. A larger bandwidth can be provided by a still further increase in the width of the slot 22. The slot 22 supports a resonant electromagnetic field composed of two component fields each of which is excited by energy coupled into the slot 22 respectively from the feed elements 28 and 30. The operation in the frequency range of approximately 10 to 11 gigahertz is obtained with the embodiment of FIG. 1 having the following dimensions: an outer diameter of the annular slot 22 of 0.40 inches; an inner diameter of 0.28 inches; and a spacing between the front plate 20 and back plate 24 of 0.125 inches and a feed element width of 0.085 inches. The plates 20 and 24 and the feed elements 28 and 30 are formed from copper foil having a weight of 1 to 2 ounces per square foot. The two feed elements 28 and 30 extend beneath the disk 31 a small distance of 0.60 inches, corresponding to approximately one-tenth wavelength of the radiation propagated in the dielectric, for improved coupling of electromagnetic energy into the slot. An annular slot can also be placed in the back plate 24 as shown in the alternative embodiment of FIG. 3 to provide an antenna having two radiating apertures.

A component of the electromagnetic field in the slot 22, excited by the feed element 28, is shown diagrammatically in FIG. 4 in which the arrows or vectors, directed radially across the slot 22 show the direction of the electric field and the length of the arrows represents the magnitude of the electric field. It is evident from FIG. 4 that the magnitude of a single component field varies substantially sinusoidally with position around the circumference of the slot 22. Due to the sinusoidal variation in the amplitude, each electric field vector has the same direction and magnitude as the vector located in the diametrically opposite portion of the slot 22. The summation of these vectors produces the resultant electric field vector shown in the center of FIG. 4. In the same way, the component field, not shown, excited by feed element 30 which is perpendicular to feed element 28 has a resultant electric field vector which is perpendicular to the aforementioned resultant electric vector excited by feed element 28. It is further shown in FIG. 4 that one end of feed element 30 is positioned beneath the slot 22 at a point where the field excited by feed element 28 has essentially zero magnitude. By symmetry, it is apparent that the electric field excited by feed element 30 will have essentially zero magnitude at the point where feed element 28 passes beneath the slot 22. Since the field excited by one feed element has essentially zero magnitude at the other feed element, the two electric fields are substantially decoupled from each other and accordingly can be generated independently of each other. The radiation radiated from slot 22 of the antenna, therefore, has a polarization given by the vector sum of the two resultant electric fields due to feed elements 28 and 30.

In operation, therefore, when electromagnetic radiation whose wavelength approximates the circumference of slot 22 is introduced into coaxial adapters 32 and 34, the slot resonates and emits radiation into the region in front of the aperture and particularly in a direction substantially perpendicular to the front and back plates. Radiation from the annular slot is provided with orthogonal linear polarizations or a continuously variable polarization such as circular or elliptical polarization in accordance with the relative phase and amplitude of electromagnetic signals applied to the strip conductor fields.

The antenna is readily fabricated. For example, the embodiment shown in FIG. 1 is fabricated from two sections of copper clad dielectric board using well-known magnetic etching techniques. Thus, with reference to FIGS. 1 and 2, a first section comprising the front plate 20, slot 22, dielectric layer 26A and the two feed elements 28 and 30 is formed from a single piece of copper clad dielectric, the annular slot 22 being etched out of the copper foil on one side of the dielectric material, the remaining foil including central disk 31 and serving as the front plate 20. The two feed elements 28 and 30 are formed on the other side of the dielectric material by etching away the portions of the copper foil surrounding the feed elements. The second section of the antenna comprising dielectric layer 26B, the back plate 24, and the mounting ports 36 for each of the two well-known stripline-to-coaxial cable adapters 32 and 34 is formed from a second piece of copper clad dielectric, the copper foil on one side of the dielectric being completely etched away, and the two mounting ports 36 being formed on the other side by etching the copper foil which serves as the back plate 24. Two sections are then pressed together to form the antenna, and coaxial cable adapters 32 and 34, which are shown in FIG. 2, are attached to the mounting ports 36 by means of metallic bolts 38 and nuts 39 which also serve to bind the two sections together. The mounting port 36 being an aperture in the copper foil leaves an insulated region of back plate 24, as shown in FIG. 2, by which the center conductor 40 of a coaxial cable adapter, such as adapter 32, can pass through the copper foil. A hole 42 drilled through dielectric layer 26B is also provided through which center conductor 40 makes electrical contact with a feed element such as the feed element 28. As the two sections are pressed together, the feed elements 28 and 30 are pressed into the dielectric layers 26A and 26B along both sides of the interface of these two layers, producing a slight recession 44 in the dielectric in the immediate vicinity of each feed element, the recession 44 having little or no effect on the operation of the antenna.

It is desirable to insert electrically conducting pins 46 around the annular slot 22, as shown in FIGS. 1 and 2, to retain the electromagnetic energy in the vicinity of the slot 22 rather than permitting the energy to propagate between the front plate 20 and the back plate 24 away from the annular slot 22. These pins 46 extend from the front plate 20 to the back plate 24 and are spaced apart with a spacing which is typically less than one-quarter wavelength of the radiation propagated within the dielectric layers 26A and 26B. The metallic bolts 38 which form a part of adapter 32 and of adapter 34 also serve in the same manner to retain the electromagnetic energy in the vicinity of the coaxial cable adapters 32 and 34.

Referring now to FIG. 5, there is shown a portion of an isometric view of an alternative embodiment of the invention having a generally annular radiating aperture of uniform width provided by a continuous slot 48 having edges which are uniformly spaced apart, each edge of the slot 48 being a closed outline or closed curve in the form of a square. The same feed elements 28 and 30 are utilized here as in the preceding embodiments. The generally annular slot 48 functions in the same manner as the annular slot 22 and supports an electromagnetic field in which the electric field vectors are transverse to the slot and have a magnitude which varies sinusoidally with circumferential distance along the slot. Thus, each feed element of FIG. 5, as with the embodiment of FIG. 1, is located at a null of the component waveform excited by the other feed element so that the two feed elements are
orthogonal and are substantially electromagnetically decoupled. The individual field vectors of the embodiment of FIG. 5 are designed to give a resultant polarization and directivity pattern to the radiating electromagnetic energy which is substantially the same as that provided by the antenna of FIG. 1.

Referring now to FIG. 6, there is shown a portion of a plan view of an alternative embodiment of the invention having a pair of feed elements 50 each with a right angle tab or bend 51 which forms the terminus of the feed element 50 at the radiating aperture. In this embodiment, the elements 50 extend only partially beneath the annular slot 22 and couple electromagnetic energy into the slot. The dimensions of the feed element 50 and its spacing relative to the slot 22 differ from the dimensions and spacing of the feed elements 28 and 30 of the preceding embodiments, and, therefore, the impedance presented to coaxial adapters, not shown, by the feed element 50 differs from that presented by the elements 28 and 30. As is well known, the impedance depends on the geometry of the feed elements and the slot, and is, therefore readily selected by an appropriate choice of dimensions such as the slot width and the spacing between the slot and a feed element. Selection of the feed element is a convenient way of providing the correct impedance for maximum power transfer from the feed element to the radiating aperture. As is well known, the antenna is reciprocal with respect to transmitted and received power so that a feed structure which provides for maximum coupling of power to the annular slot on transmission is also well suited for coupling received electromagnetic energy from the annular slot to the feed structure.

The annular slot antenna 18 can alternatively be constructed in a further embodiment, as shown in the plan view and sectional view presented respectively in FIG. 7 and FIG. 8, having a solid dielectric 52, a low-loss material such as a well-known mixture of Teflon-fiberglass which supports front plate 53, feed element 54 and back plate 55. In this embodiment the feed element 54 is terminated by means of a shorting bar 56 in the form of an electrically conducting rod in electrical contact with both the feed element 54 and the central disk 57 enclosed by the annular slot 22, as shown in FIG. 7. The distance along element 54 between bar 56 and slot 22 is approximately one-quarter wavelength of the radiation propagated within the dielectric medium so that the impedance of the bar 56 reflected back to the slot 22 approximates the open circuit provided by the feed elements 28 and 30 of FIG. 1.

Each of the embodiments which have been described are of the stripline form; that is, they contain two uniformly spaced electrically conducting plates which can be flat or curved and a central dielectric medium uniformly spaced between the two metal plates. With reference to FIG. 1, the antenna is still operable if the back plate 24 is removed, leaving an embodiment of the invention in the form of microstrip, that is, a single flat or curved conducting plate containing a radiating aperture and a feed element uniformly spaced relative to the plate to support an electromagnetic traveling wave.

An example of a microstrip embodiment of the invention is presented in FIGS. 9 and 10 which show, respectively, a sectional view and an auxiliary view of such embodiment. In addition, this embodiment serves as an example of construction utilizing an air dielectric and shorted quarter-wavelength transmission line support elements 58 to position feed element 60 and electrically conducting disk 62 in conducting plate 64. The plate 64 and feed element 60 are constructed from rigid electrically conducting material, preferably copper, and are uniformly curved and positioned with respect to each other to support a traveling electromagnetic wave from coaxial cable adapter 66 to annular slot 68. The adapter 66 is affixed to plate 64 by means of mounting bolts 70 and nuts 72 in a position whereby the center conducting electrode 74 of adapter 66 makes electrical contact with feed element 60. Since this embodiment of the antenna has one feed element, the antenna radiates linearly polarized radiation. It is understood that this embodiment can readily be modified by the inclusion of a second feed element and coaxial cable adapter, not shown, whereby the antenna would radiate radiation having a variable polarization.

Referring now to FIG. 11, there is shown a means, partially in block diagram form, for supplying electromagnetic energy to the antenna 18 of FIG. 1 comprising a source of electromagnetic energy, such as an X-band signal source 76, a variable attenuator 78 for attenuating the signal provided by source 76 and transferring the attenuated signal coaxial cable 80 to coaxial cable adapter 32, and a well-known variable phase shifter 82 for phase shifting the signal provided by source 76 and transferring the phase shifted signal to a second attenuator 84 which attenuates the phase shifted signal to a second feed element and transfers the attenuated phase shifted signal coaxial cable 86 to coaxial cable adapter 34. By means of the two attenuators 78 and 84, a relative difference is provided in the amplitudes of the two signals applied, respectively, to the adapters 32 and 34. Thereby, two X-band signals differing in amplitude and phase, but having the same frequency, are applied to the antenna, one signal provided respectively for each feed element. By a well-known variation in the phase and amplitude, the polarization of radiation from the antenna can be made to vary from circular to elliptical to orthogonal linear polarization.

Referring now to FIG. 12, there is shown a novel method for combining the radiation patterns from an array of annular slot antennas 18, two of which are shown in FIG. 12, utilizing the capability for independently exciting the feed elements of each pair of feed elements in the antennas 18. A source of microwave energy, such as the source 76 which is adapted to radiate through horn 88 connected to source 76 by waveguide 90, transmits radiation having a fixed linear polarization simultaneously to the antennas 18. Each antenna is positioned such that one feed element is parallel to the direction of polarization, that is, parallel to the electric field of the radiation, and the second feed element is perpendicular to the polarization whereby radiation is received by the first feed element while substantially no radiation is received by the second feed element. In each antenna, one feed element is used for receiving electromagnetic energy while the second feed element, being electromagnetically decoupled from the first feed element, is capable of simultaneously transmitting electromagnetic energy. Electromagnetic signals received by the first feed element in each of the antennas 18 are then conveyed by cables 80 to variable phase shifters 82 which impart phase shifts to each of these signals. The phase shifted signals are then conducted via cables 86 to the second feed element in each of the antennas 18 for subsequent radiation from each of the antennas 18. Alternatively, a more compact form of phase shifter, not shown, can be employed which is constructed of well-known stripline components, usually by photomasking techniques to provide inductive and capacitive elements from conducting materials, such as copper foil embedded in a dielectric material between two conducting surfaces, so that, for example, the stripline form of phase shifter can conveniently be incorporated within the structure of antenna 18 in which the plates 20 and 24 shown in FIG. 1 also serve as the outer conducting plates of the phase shifter. The resulting radiation pattern which is formed in accordance with well-known principles from contributions of radiation from each of the antennas 18 in the array can be fixed or varied at will in accordance with the phase shifts imparted to the electromagnetic signals by each of the variable phase shifters 82.

Referring now to FIG. 13, there is shown a relatively simple method of mounting an annular slot antenna to radiate into the end portion of a circular waveguide. For example, a portion of waveguide 92 is shown having a mounting flange 94 and clamps 96 for holding the annular slot antenna 18 in position for radiating into the waveguide 92. In this way, the antenna 18 serves to launch one or more waveguides which have a polarization corresponding to the polarization of the radiation emitted by the antenna. The antenna is conveniently energized through coaxial cables 97, partially shown
in FIG. 13, with signals provided by well-known signal sources, not shown. In this embodiment of the invention, the antenna 18 serves as a dual coaxial cable to waveguide transition for orthogonal TE_{11} modes in circular waveguide.

Referring now to FIG. 14, there is shown a diagrammatic representation of a novel method for dissecting and reforming a radiation pattern. This method utilizes the capability of the annular slot antenna 18 for permitting independent excitation of its two feed elements as well as the antenna capability for transmitting and receiving radiation having linear, circular, and elliptical polarizations. As shown in FIG. 14, three annular slot antennas 18 are positioned in an array 98 to receive radiation, and a second group of three annular slot antennas 18 are positioned in a second array 100 to transmit radiation. A source of electromagnetic energy, preferably having a horn-type radiator, such as the source 102 emits radiation towards the array 98 of the three antennas 18 which are positioned to receive portions of the rays of radiation indicated by arrows 104. The perpendicularly disposed feed elements in each antenna 18 of array 98 resolve the received radiation in perpendicularly components such as for example, horizontal and vertical components which are then passed through phase shifters respectively 106A and 106B. These phase shifters which are preferably of the well-known variable phase type providing a phase shift in response to a control signal, not shown, impart a phase shift to the horizontal and vertical components of the received radiation which are then fed respectively to the horizontal and vertical components of antennas 18 in array 100 for subsequent transmission. The resulting pattern of the radiation from the antennas of the array 100 is composed from contributions of radiation from each of the antennas 18 in the array 100 and can be fixed or varied at will in accordance with the relative positions of the antennas 18 within the two arrays, and in accordance with the phase shifts imparted by the phase shifters 106A and 106B to the horizontal and vertical components of the radiation.

The use of phase shifters 106A and 106B of the variable type is demonstrated by an example in which the source 102 transmits a clockwise circular polarization and each phase shifter 106A is adjusted in a well-known manner to impart a phase shift which differs by 180° from that imparted by each shifter 106B to give a resultant radiation from the antennas of array 100 having a counterclockwise circular polarization. As a further example, attenuators, not shown, can now be connected to the outputs of phase shifters 106B to alter the relative amplitudes of the horizontal and vertical components to provide in a simple manner elliptical polarization to radiation from the elements of array 100. Alternatively, one or more pairs of phase shifters 106A and 106B can impart equal phase shifts while other pairs of shifters 106A and 106B impart phase shifts differing by 180° so that a portion of the clockwise circularly polarized radiation of source 102 is modified to counterclockwise polarized radiation while the remaining portion retains the clockwise polarization. In this manner, circularly polarized radiation of one sense can be readily converted into radiation having circular polarization of both senses. As a still further example, the directivity patterns of the horizontal and vertical components of the radiation emitted from a given arrangement of the annular antenna 18 in array 100 can be individually varied in response to the differences in phase shift imparted respectively by the shifters 106A and 106B. In this manner, substantially separate directivity patterns can be formed which are respectively characterized by the horizontal and vertical components of a received radiation.

It is understood that the above-described embodiments of the invention are illustrative only and that modifications thereof will occur to those skilled in the art. Accordingly, it is desired that this invention is not to be limited to the embodiment disclosed herein but is to be limited only as defined by the appended claims.

I claim:

1. An antenna for radiating electromagnetic radiation comprising a plurality of electrically conducting plates, at least one of said plates being provided with an opening having a closed outline, an electrically conducting member of smaller dimensions than said opening supported within said opening such that the boundary of said member which has substantially the same form as said closed outline is aligned with the boundary of said opening to form a radiating aperture, a plurality of feed elements supported by means of at least one dielectric support structure in spaced relation to said conducting plates to couple electromagnetic energy into said radiating aperture, said feed elements being positioned about the circumference of said radiating aperture to provide a continuously variable polarization to radiation radiated from said aperture.

2. An antenna comprising two substantially parallel electrically conducting plates in spaced apart relationship, a generally annular radiating aperture of substantially uniform width provided in at least one of said conducting plates, a plurality of feed elements supported by means of a dielectric support structure in spaced relation between said conducting plates to couple electromagnetic energy into said radiating aperture, said feed structures being positioned about the circumference of said radiating aperture to provide a continuously variable polarization to radiation radiated from said aperture.

3. An antenna comprising first and second feed elements supported in spaced relationship between two substantially parallel conducting plates by means of a dielectric support structure, at least one of said conducting plates having a radiating aperture in the form of an annular slot having substantially uniform width and a circumference which permits said slot to support at least one resonant mode of electromagnetic radiation radiated from said aperture, said first feed element being positioned relative to said slot to couple electromagnetic energy into said slot, said second feed element being positioned at a null of the resonant waveform excited in said slot by said first feed element so that said second feed element couples electromagnetic energy into said slot independently of the energy being coupled by said first feed element.

4. The antenna of claim 3 including a plurality of electrically conducting pins disposed with substantially equal circumferentially around said slot to reduce the propagation of radiation between said conducting plates radially outwards from said slot.

5. The antennas of claim 3 including a variable phase shifter connected electrically between said first and second feed elements whereby radiation having a first polarization received by said first feed element is phase shifted by said variable phase shifter and transmitted by said second feed element at a second polarization.

6. An antenna comprising an electrically conducting plate having a generally annular radiating aperture of substantially uniform width enclosing a central disk which is supported by a metallic shorted quarter-wave transmission line segment, a plurality of microstrip feed elements in parallel spaced relationship to said conducting plate which are supported by a plurality of metallic shorted quarter-wave transmission line segments to couple electromagnetic energy into said radiating aperture, said feed elements being positioned about the circumference of said radiating aperture to provide a continuously variable polarization to radiation radiated from said aperture.

7. An antenna comprising first and second feed elements supported by means of a dielectric support structure in parallel spaced relationship to an electrically conducting plate, said conducting plate having a radiating aperture in the form of a generally annular slot having a substantially uniform width and adapted to support at least one resonant mode of electromagnetic radiation radiated from said aperture, said first feed element being positioned relative to the electromagnetic energy into said slot, said second feed element being positioned at a null of the resonant waveform excited in said slot by said first feed structure so that said second feed element couples electromagnetic energy into said slot independently of the energy being coupled by said first feed element.
8. In combination:
a source of electromagnetic energy emitting radiation hav-
ing a first polarization;
a plurality of antennas each of which comprises at least one
electrically conducting plate provided with an opening
having a closed outline, an electrically conducting
member supported within said opening such that the
boundary of said member which has substantially the
same form as said closed outline is aligned with the
boundary of said opening to form an aperture for receiving
radiation having said first polarization and transmitting
radiation having a second polarization, said aperture
being positioned to receive a portion of the electromag-
netic energy emitted by said source of electromagnetic
energy, first and second feed elements having at least por-
tions thereof substantially uniformly spaced from said
conducting plate to support respectively first and second
electromagnetic traveling waves which travel respectively
from and towards said aperture, said second feed element
being positioned to excite a resonant mode of elec-
 tromagnetic radiation within said aperture, said first feed
element being positioned at a null of said resonant mode
to couple from said aperture radiation of said first polar-
ization;
a plurality of variable phase shifters, one of said variable
phase shifters being connected between an output of said
first feed element and an input of said second feed ele-
ment to impart a phase shift between said first and second
traveling waves;
each of said antennas being positioned to transmit radiation
having said second polarization in a common direction to
provide a resultant radiation pattern formed in ac-
cordance with the phase shifts imparted by said phase
shifters.

9. In combination:
a source of electromagnetic energy emitting radiation hav-
ing a first polarization;
a plurality of antennas each of which comprises at least one
electrically conducting plate provided with a generally
annular radiating aperture having a circumferential length
which permits first and second orthogonal electric
fields to be supported within said aperture, a first feed
element positioned relative to said aperture for coupling
electromagnetic energy from said first orthogonal field, a
second feed element positioned relative to said aperture
for coupling electromagnetic energy into said aperture to
excite said second orthogonal field, said first orthogonal
field being excited by radiation having said first polariza-
tion received from said source of electromagnetic energy;
a plurality of phase shifters one of which is connected
between said first and second feed elements of each an-
tenna whereby radiation provided by said first feed ele-
ment is phase shifted and coupled to said second feed ele-
ment;
each of said antennas being positioned to transmit radiation
of a second polarization emanating from each of said
second orthogonal fields in a common direction to pro-
vide a resultant radiation pattern formed in accordance
with the phase shifts imparted by said phase shifters.

10. In combination:
antenna means comprising a plurality of electrically con-
ducting plates provided with radiating apertures and posi-
tioned to receive radiation of a first polarization arriving
from a common source, a first feed element respectively
positioned relative to each of said apertures and extend-
ing substantially normally therefrom to couple energy
from received radiation of said first polarization, a second
feed element coupled to each of said apertures to excite
radiation of a second polarization in said apertures for
transmission therefrom, each of said second feed ele-
ments respectively spaced along each of said apertures from
each of said first feed elements whereby each of said first and second feed elements are
substantially electromagnetically decoupled;
a plurality of phase shifters respectively connected to each
of said first feed elements to impart phase shifts to radia-
tion provided by each of said first feed elements, the out-
puts of said phase shifters being connected respectively to
each of said second feed elements whereby radiation of
said second polarization is phase shifted relative to the
phase of radiation of said first polarization for forming a
combined radiation pattern of the transmitted radiation of
said second polarization.

11. In combination:
at least one antenna which comprises first and second feed
elements supported in spaced relationship between two
substantially parallel conducting plates by means of a
dielectric support structure, at least one of said conduct-
ing plates having a radiating aperture in the form of a
generally annular slot of substantially uniform width and
circumferential length to permit said slot to support at
least one resonant mode of electromagnetic radiation
radiated from said aperture, said first feed element being
positioned relative to said slot to couple electromagnetic
energy into said slot, said second feed element being posi-
tioned at a null of the resonant waveform excited in said
slot by said first feed element so that said second feed ele-
ment couples electromagnetic energy into said slot inde-
pendently of the energy being coupled by said first feed
element; and
wavelength means equipped with mounting means at one
end thereof whereby each of said antennas is mounted in a
position to couple electromagnetic energy into said
wavelength means.

12. In combination:
a source of electromagnetic radiation;
a plurality of receiving antennas positioned to receive radia-
tion from said source of electromagnetic radiation, each
of said receiving antennas comprising at least one electric-
ally conducting plate provided with an opening having a
closed outline, an electrically conducting member of
smaller dimensions than said opening supported within
said opening such that the boundary of said member
which has substantially the same form as said closed out-
line is aligned with the boundary of said opening to form a
receiving aperture for receiving electromagnetic radia-
tion, at least one feed element positioned relative to said
receiving aperture whereby a component of the received
field of the radiation provided by said source of elec-
tromagnetic radiation induces a received signal in said
feed element, said receiving feed element being spaced
relative to said conducting plate whereby said received
signal propagates along said feed element from said
receiving aperture;
a plurality of phase shifters each of which is coupled respec-
tively to feed elements of said receiving antennas for im-
parting phase shifts respectively to each of said received
signals;
a plurality of transmitting antennas each of which comprises
at least one electrically conducting plate provided with an
opening having a closed outline, an electrically conduct-
ing member of smaller dimensions than said opening sup-
ported within said opening such that the boundary of said member which has substantially the same form as said
closed outline is aligned with the boundary of said open-
ning to form a transmitting aperture for transmitting elec-
tromagnetic radiation, at least one transmitting feed ele-
ment positioned relative to said transmitting aperture to
excite therein a component of the transmitted field of
electromagnetic radiation, said transmitting feed element
being spaced relative to said conducting plate whereby
electromagnetic energy for said transmitted component
field propagates along said transmitting feed element to
said transmitting aperture; and
the outputs of each of said phase shifters being connected re-
spectively to each feed element of each of said trans-
mitting antennas for coupling thereto electromagnetic
energy of each of said components of said received radiation, said transmitting antennas being positioned to radiate in a common direction whereby the radiations from each of said transmitting antennas sum together to provide at least one resultant radiation pattern which is formed in accordance with the phase shifts imparted by said phase shifters to said received signals.

13. In combination:

a source of electromagnetic radiation;
a plurality of receiving antennas which are positioned to receive said radiation, a plurality of phase shifters, a plurality of transmitting antennas, each of said receiving and transmitting antennas having an annular slot radiating aperture disposed within a conducting plate, said aperture being coupled to a pair of orthogonal feed elements which are uniformly spaced with respect to said plate for exciting within said aperture orthogonal electric fields having sinusoidal amplitude distributions around the circumference of said radiating aperture;
the two feed elements in each of said receiving antennas being connected, respectively, to a pair of phase shifters to couple respective components of the received electromagnetic field from the radiating aperture into the respective phase shifters to provide a corresponding pair of phase shifted electromagnetic signals;
the two feed elements in each of said transmitting antennas being positioned to couple corresponding pairs of said phase shifted electromagnetic signals from pairs of said phase shifters into the radiating aperture in each of said transmitting antennas to excite within the aperture of each of said transmitting antennas corresponding components of an electromagnetic field for subsequent transmission;
each of said transmitting antennas being positioned to radiate in a common direction whereby the radiations from each of the orthogonal electric fields within the radiating apertures of said transmitting antennas sum together to provide at least one resultant radiation pattern which is formed in accordance with the phase shifts imparted by said phase shifters to said received signals.

14. An antenna for radiating electromagnetic radiation comprising at least one electrically conducting plate provided with an opening having a closed outline, an electrically conducting member of smaller dimensions than said opening supported within said opening such that the boundary of said member which has substantially the same form as said closed outline is aligned with the boundary of said opening to form an aperture which can support a resonant mode of electromagnetic radiation having a wavelength approximately equal to the length of said aperture, at least one feed element having at least a portion thereof substantially uniformly spaced from said conducting plate to support an electromagnetic wave which propagates toward said aperture, said feed element terminating adjacent one point of said aperture to couple electromagnetic energy from said feed element to said aperture such that the electromagnetic radiation resulting from the interaction of said feed element and said aperture is polarized in a single direction.

15. In combination:

a plurality of receiving antennas positioned to receive electromagnetic radiation from a common source of electromagnetic radiation and a plurality of transmitting antennas positioned to radiate at least a portion of their individual radiations in a common direction, each of said receiving antennas and each of said transmitting antennas comprising at least one electrically conducting plate provided with an opening having a closed outline larger than a wavelength of said radiation, an electrically conducting member of smaller dimensions than said opening supported within said opening such that the boundary of said member which has substantially the same form as said closed outline is aligned with the boundary of said opening to form a radiating aperture which can support a resonant mode of said radiation;
a plurality of feed elements positioned relative to said aperture for coupling electromagnetic radiation to said aperture, said feed elements being spaced relative to said conducting plate to permit electromagnetic radiation to propagate along said feed elements to couple with said aperture; and

a plurality of groups of phase shifters, each of said group of phase shifters interconnected one of said receiving antennas to one of said transmitting antennas such that each of said phase shifters in said group of phase shifters interconnects a feed element of said receiving antenna with a corresponding feed element of said transmitting antenna for coupling electromagnetic energy from said receiving antenna to said transmitting antenna, each of said phase shifters imparting individual phase shifts to electromagnetic energy coupled by said phase shifter for varying the polarization of said radiation transmitted by said transmitting antennas relative to the polarization of radiation received by said receiving antennas.

* * * * *