Sept. 5, 1967 M. L. FEE 3,340,534

ELLIPTICALLY OR CIRCULARLY POLARIZED ANTENNA

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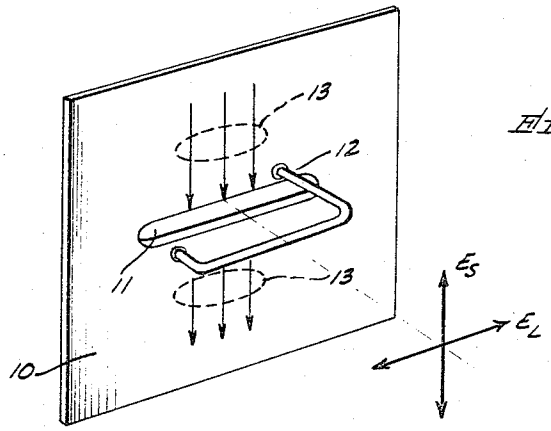


FIG. 1.

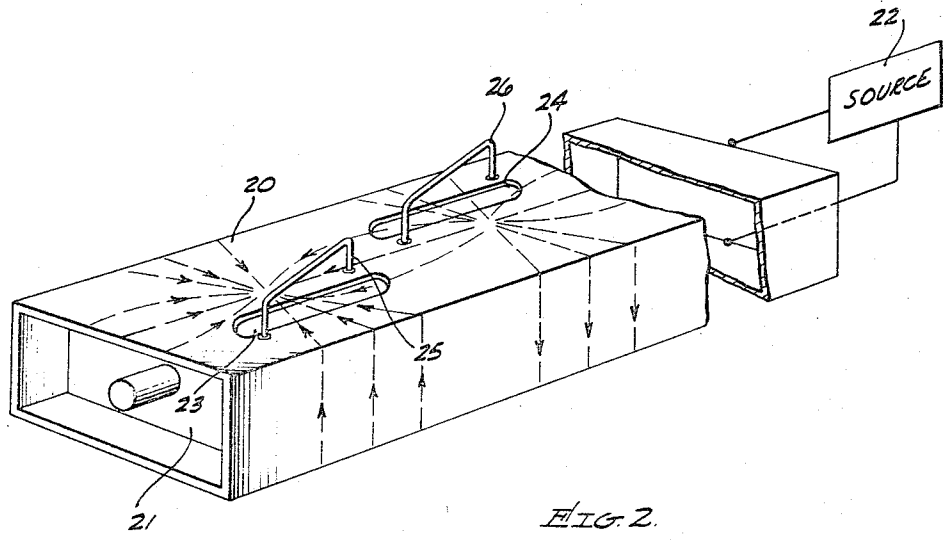


FIG. 2.

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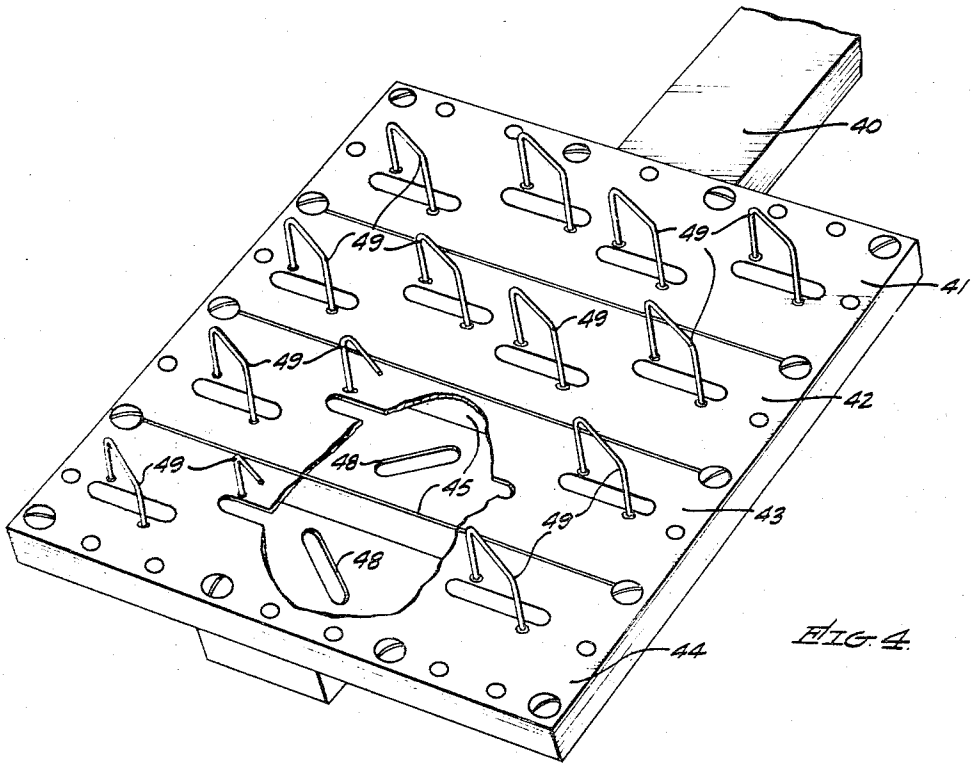


FIG. 4.

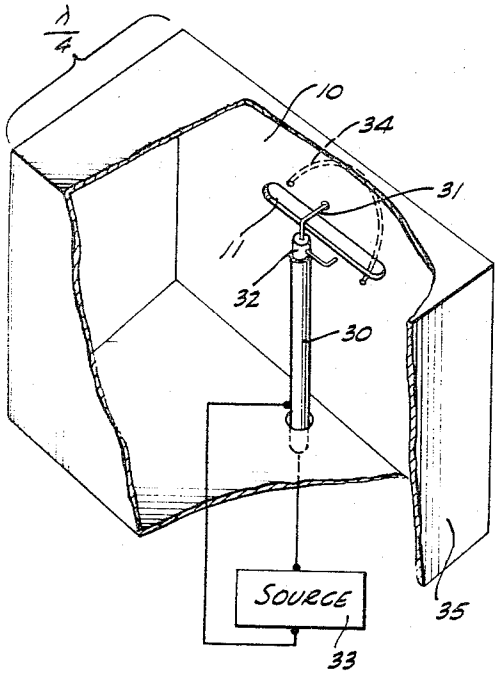


FIG. 3.

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United States Patent Office 3,340,534 Patented Sept. 5, 1967

3,340,534 ELLIPTICALLY OR CIRCULARLY POLARIZED ANTENNA

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Filed Sept. 22, 1965, Ser. No. 489,223
10 Claims. (Cl. 343—728)

This invention relates to high-frequency antennas and more specifically to antennas capable of radiating and receiving elliptically and circularly polarized wave energy.

In some applications, such as space communications systems, it is desirable to utilize antennas which radiate and receive elliptically or circularly polarized electromagnetic wave energy. This stems from the fact that with linearly polarized waves accurate coplanar polarization of the receiving and transmitting antennas is required for optimum transmission. Quite often it is difficult, if not impossible, to accurately maintain such polarization alignment. Circular poralization is therefore desirable since it obviates the necessity of polarization alignment between antennas.

It is a general object of the present invention, therefore, to provide antenna devices for radiating and receiving circularly and elliptically polarized electromagnetic wave energy.

In the past, circularly polarized high-frequency antennas have generally utilized a basic radiating element comprising a form of aperture in a waveguide wall. Apertures in the form of circular holes or crossed slots cut into the broad wall of a rectangular waveguide at a proper location will yield circular polarization. See, for example, the article, "Circularly Polarized Slot Radiators," by A. J. Simmons, IRE Transactions on Antennas and Propagation, vol. AP–5, No. 1, January 1957, at pages 31 et seq.

In particular, in order to obtain increased directivity, an array consisting of a plurality of crossed slots longitudinally spaced along a waveguide wall has been utilized. To obtain uniformity in the sense of polarization with such an array, the interelement spacing must be substantially equal to one guide wavelength. However, when such a wide spacing is utilized, undesirable side lobes of relatively high magnitude occur in the radiation pattern of the array.

Several methods have been suggested for overcoming the problems caused by wide interelement spacing. One such method requires that the waveguide be loaded with a dielectric material in order to reduce the effective guide wavelength. This solution, however, increases the weight of the array and introduces dielectric losses which, in turn, reduce the antenna efficiency.

It is, therefore, a further object of the present invention to decrease the interelement spacing in a circularly polarized array antenna without decreasing the antenna efficiency.

Prior art crossed slot array antennas are also generally of the traveling-wave variety. That is, the electromagnetic wave energy propagates in one direction within the waveguide containing the slots. To insure such unilateral propagation, the guide is generally terminated in a reflectionless load impedance. The load impedance, therefore, dissipates power which again decreases the antenna efficiency. For this reason, it is frequently desirable to utilize an antenna capable of standing-wave operation, which has no dissipative load impedance.

Accordingly, it is yet another object of the present invention to provide traveling-wave or standing-wave operation in circularly and elliptically polarized antennas.

The above-mentioned objects are accomplished in accordance with the present invention by utilizing a basic

radiating element comprising a slot and conductive loop across the slot. The radiating element can be energized, for example, by the wall currents set up in a hollow waveguide in the same manner as a simple waveguide slot antenna. The wall currents excite the slot so that the electric vector of the energy radiated therefrom is polarized in a plane perpendicular to the longer dimension of the slot. The electric vector of the energy radiated from the loop, on the other hand, is polarized in a plane substantially parallel to the longer dimension of the slot. By virtue of the geometry of the loop-slot combination, the phase centers of the two radiated waves are different. Specifically, the phase center of the energy radiated from the slot is in the plane of the slot, whereas the phase center of the energy radiated from the loop is a fraction of a wavelength away from the plane of the slot. Elliptically polarized wave energy is thereby radiated from the combined loop-slot element. By selecting the proper length, shape and connection points of the loop, circular polarization is obtained.

In order that the present invention may be clearly understood and readily carried into effect, it will now be described with reference by way of example to the accompanying drawings, in which:

FIGURE 1 is a pictorial illustration of a basic radiating element in accordance with the present invention;

FIG. 2 is a pictorial illustration, partially broken away, of an embodiment of the present invention utilizing a rectangular waveguide;

FIG. 3 is a pictorial illustration, partially broken away, of another embodiment of the present invention utilizing a coaxial transmission line feed; and

FIG. 4 is a pictorial illustration, partially broken away, of a planar array antenna in accordance with the present invention.

Referring more specifically to the drawings, in FIG. 1 there is shown a thin wafer **10** of substantially rectangular transverse dimensions. The wafer **10** is fabricated of a material such as copper having a high electrical conductivity at microwave frequencies. An elongated aperture or slot **11** extends through wafer **10** in the approximate center thereof. The dimensions of slot **11** are determined by the frequency range over which the device is intended to operate. In general, the longer dimension of slot **11** is substantially equal to one-half wavelength at the mid-frequency of the operating range and the narrow dimension is yet a smaller fraction of this wavelength. A loop **12** of conductive wire is mechanically and electrically connected across the longer sides of slot **11** so that, advantageously, the loop lies in a plane substantially parallel to the longer dimension of the slot. Due to the small narrow dimension of slot **11**, it is seen that loop **12** is only substantially, not exactly, parallel to the larger dimension thereof. It has been found, however, that this relatively minor misalignment does not significantly affect the operation of this and other embodiments of the present invention. If desired, however, loop **12** can be bent or twisted into exact alignment.

Each end of loop **12** is soldered, brazed, welded or otherwise secured in position adjacent the long edges of slot **11** a short distance from the ends thereof. The perimeter of loop **12** can conform to a substantially rectangular shape, as shown, or can be oval or elliptical as desired. By the same token, the cross-sectional geometry of the wire utilized to form loop **12** can be circular, as shown, or can be of any other shape, such as square or rectangular.

In the pictorial view of FIG. 1 no feed mechanism is shown. The operation of the embodiment, however, can be readily understood by considering electric currents flowing in conductive wafer **10** perpendicular

to the long dimension of slot **11**. The currents are alternating currents having a frequency which corresponds to the frequency of the electromagnetic wave energy to be radiated. The currents can be established by an appropriate feed to be described in greater detail in connection with the embodiments of FIGS. 2–4. For the present description, however, it is sufficient to consider the currents and fields in the vicinity of the loop-slot radiating element.

At a time when the current is maximum in one direction, the current streamlines are perpendicular to the longer dimension of slot **11**, somewhat as shown by arrows **13**. Of course, during the maximum of the next half-cycle, the direction of the currents is reversed. In accordance with well known theory, the currents in wafer **10** having components perpendicular to the longer dimension of the slot set up an electric field across the narrow dimension of the slot which is then radiated into space in a direction away from wafer **10**. It is seen that the phase center of the wave thus radiated lies within the slot, and therefore, in the plane of the wafer **10**. A comprehensive treatment of slot radiation per se is given in the treatise, "Microwave Antenna Theory and Design," edited by S. Silver, M.I.T. Rad. Lab. Series, vol. 12, McGraw-Hill Book Company, Inc., 1949, at pp. 287 et seq.

Returning to the operation of the present invention the currents in wafer **10** and the electric field produced in slot **11** also produce a current in loop **12**. By virtue of this current, electromagnetic wave energy is also radiated from loop **12**. The polarization of the radiated wave energy from loop **12** is substantially parallel to the long dimension of slot **11**, due to the orientation of the loop. The wave energy radiated from slot **11**, on the other hand, is perpendicular to its long dimension and is thus essentially orthogonal to the wave energy radiated from the loop. Double-headed arrows designated E_S and E_L indicate the directions of the electric field vectors of the wave energy radiated from the slot and loop, respectively.

By way of explanation, when there is a combination of two uniform plane waves of the same frequency but having different phases, magnitudes and orientations of the electric field vectors, the resultant combination is said to be an elliptically polarized wave. If the two orthogonal waves combine so that the electric field vectors are 90° out of phase and the magnitudes are equal, then the resultant wave is said to be circularly polarized.

It is therefore seen that the wave energy radiated from the loop-slot combination of FIG. 1 is elliptically polarized. Furthermore, by proportioning loop **12** so that the phase center of the energy radiated from it is 90 electrical degrees removed from the plane of wafer **10**, circularly polarized radiation can be obtained. For circularly polarized radiation, however, the magnitudes of the two electric vectors must be equal. This is achieved by selecting the proper loop length and by properly positioning the ends of the loop along the longer dimension of slot **11**.

By way of example, a basic radiating element similar to that of FIG. 1 was designed for a frequency of operation of 2285 megacycles per second. The dimensions of the device were:

	Inches
Wafer size	4.5 x 4.25 x 0.03.
Slot size	2.50 x 0.375.
Diameter of loop wire	0.0625.
Loop perimeter	5.35.

The maximum distance between the loop and the wafer was 1.57 in. The ends of the loop were attached 0.50 in. from the ends of the slot and 0.063 in. from the longer edges.

In the experimental embodiment mentioned above, the wafer was made a part of a waveguide wall to provide the proper excitation. A similar arrangement is shown in the pictorial view of FIG. 2, wherein several loop-slot

combinations are utilized in the manner of a linear array.

In FIG. 2 a section of rectangular waveguide **20** is provided with a short-circuit at one end region. This short-circuit can comprise a stationary end wall or a movable conductive piston **21**, as shown. A source **22** of high-frequency electromagnetic wave energy is adapted for coupling to the other end of waveguide **20**. By virtue of the short circuit provided by piston **21**, the energy propagating from source **22** is reflected. The incident and reflected waves therefore combine to establish a standing-wave pattern within waveguide **20**. The wall currents set up by the standing-wave pattern are indicated by the arrows.

A plurality of elongated slots are disposed in a broad wall of waveguide **20** and are staggered along alternate sides of the broad wall center line. For the sake of clarity, only two slots **23** and **24** are shown, although it is understood that a greater number of slots can be utilized if desired. Each slot is oriented so that its longer dimension is substantially parallel to the axis of waveguide **20**. The longitudinal spacing between slots **23** and **24** and any other additional slots is substantially equal to one-half guide wavelength at the frequency of operation.

Loops **25** and **26** of conductive wire are conductively attached across each of slots **23** and **24**, respectively, so that, as before, the conductive loops lie in planes substantially parallel to the long dimensions of the slots. Each loop-slot combination is disposed in a region of the waveguide wall wherein the wall currents have components perpendicular to the longer dimension of the slots. In order to insure that the sense of the circularly or elliptically polarized radiation is the same, adjacent slots are disposed on opposite sides of the center line of the broad waveguide wall containing the slots. The degree of coupling and therefore the amount of energy radiated from each loop-slot element is primarily determined by the transverse distance between the element and the waveguide center line. In particular, the energy radiated from loop-slot element **23–25** would be substantially zero if the slot were in the center line of the waveguide wall, and would increase if the element were moved transversely toward one of the narrow walls.

The wall currents shown in FIG. 2 correspond to those produced by wave energy propagating in the TE_{10} mode. It is apparent, however, that other modes can be utilized. It is also apparent to those skilled in the art that the particular placement and orientation of slots **23** and **24** together with their associated loops **25** and **26** are merely illustrative. It is well known that slot radiators can be arrayed so that the slots are oblique to the waveguide axis or are disposed in a narrow wall of the waveguide.

The embodiment of FIG. 2 can also be adapted for traveling-wave operation. If such operation is desired, conductive piston **21** can be replaced by a non-reflective load impedance. Such a modification would result in substantially unilateral propagation of wave energy through waveguide **20**.

An alternate method of feeding a radiating element according to the invention is shown in FIG. 3. Where appropriate, like reference numerals have been carried over from FIG. 1 to designate like elements. In FIG. 3 a loop-slot radiating element is fed by means of a section of coaxial transmission line **30**. The inner conductor **31** of coaxial line **30** is conductively connected to one side of slot **11**, and the outer conductor **32** is connected to the opposite side. A source **33** of high-frequency electromagnetic wave energy is connected to the opposite end of coaxial line **30** either directly, as shown, or through a switching device well known in the art.

In the embodiment of FIG. 3 a loop **34** of substantially elliptical shape is shown. As mentioned hereinabove, such a shape can be utilized, and in some instances may be preferable to a rectangularly shaped loop. In any event, the operation of the embodiment of FIG.

3 is substantially identical to that of the embodiment of FIG. 1.

In order to prevent the unwanted radiation of energy from the back of the wafer, a conductive enclosure **35** can be provided around the slot **11** and feed line **30**. Enclosure **35** preferably extends substantially one-quarter wavelength behind wafer **10**. Enclosure **35** in combination with wafer **10** thereby forms a conductively bounded cavity. If desired, enclosure **35** can be fitted with a movable wall or piston, for tuning purposes.

In FIG. 4 there is shown a further embodiment of the present invention. The embodiment of FIG. 4 comprises a plurality of loop-slot radiating elements arranged in the manner of a planar array antenna. In this embodiment a section of rectangular waveguide **40** comprises the feed for the array. Four secondary sections of rectangular waveguide **41, 42, 43** and **44** are disposed adjacent one of the broad walls of feed guide **40** so that their axes are substantially perpendicular to the axis of the feed waveguide **40**. Advantageously, secondary waveguide sections **41, 42, 43** and **44** are arranged contiguously so that common narrow walls **45** can be used between adjacent pairs. The same result can be obtained, by utilizing one large cavity and by partitioning it with walls **45** to form the secondary waveguide sections.

Elongated apertures of slots **48** are formed in the bottom wall of each secondary waveguide section **41, 42, 43** and **44** and extend through the adjacent top wall of feed waveguide **40**. Slots **48** oriented at an angle to the axis of feed waveguide **40** serve to couple the microwave energy from the feed waveguide to each of the secondary waveguides.

Disposed in the opposite broad walls of secondary waveguide sections **41, 42, 43** and **44** are a plurality of loop-slot radiating elements **49** similar to those described with respect to FIG. 2. In order to insure proper phase among the individual elements, alternate loop-slot combinations are staggered on opposite sides of the secondary waveguide center lines. The number of loop-slot radiating elements, the position of these elements with respect to their respective waveguide center line and the relative amplitude and phase of the energy coupled to each secondary guide determine the cross-sectional shape of the circularly polarized radiation pattern of the array. Beam shaping by varying the geometric arrangement of individual radiating elements and the coupling slots feeding the secondary guides of a planar array is well known to those skilled in the art. In general, an antenna array contemplated by this invention can comprise any number of secondary waveguides, each one containing any number of individual loop-slot radiating elements—the number of each depending upon the radiation pattern desired.

In all cases, it is understood that the abovedescribed arrangements are illustrative of but a small number of the many possible specific embodiments which can represent applications of the principles of the present invention. Numerous and varied other arrangements can be readily devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A high frequency antenna comprising, in combination:

a thin conductive wafer having an elongated slot extending therethrough;

a loop of conductive wire conductively connected across the longer sides of said slot, at least a substantial portion of said loop being disposed in a plane substantially parallel to the longer dimension of said slot; and

means for inducing an alternating electric current in said conductive wafer, said current having components in a direction perpendicular to said longer dimension of said slot.

2. In combination:

a conductively bounded signal wave transmission path;

means for exciting said transmission path with electromagnetic wave energy of a given mode;

said transmission path having an outer wall defining at least one elongated slot;

each slot being oriented so that its longer dimension is substantially perpendicular to the electric current induced in said wall by said exciting means; and

a loop of conductive wire conductively connected across the longer sides of each slot, at least a substantial portion of each of said loops being disposed in a plane substantially parallel to said longer dimension of each slot.

3. In combination:

a section of conductively bounded signal wave transmission path;

means for exciting said transmission path at one end thereof with wave energy of a given mode;

means for conductively shorting the other end of said transmission path;

at least one elongated slot disposed in an outer wall of said transmission path between said ends;

each slot being oriented so that its longer dimension is substantially perpendicular to a component of the electric current in said wall; and

a loop of conductive wire conductively connected across the longer sides of each slot, at least a substantial portion of each of said loops being disposed in a plane substantially parallel to said longer dimension of each slot.

4. A high frequency antenna comprising, in combination:

a section of hollow rectangular waveguide supportive of electromagnetic wave energy over a given range of frequencies, said waveguide having a plurality of elongated slots disposed in a wall thereof and electromagnetically coupled thereto; and

a loop of conductive wire conductively connected across the longer sides of each of said slots, the projection of each of said loops on said wall being substantially parallel to the longer dimension of its corresponding slot.

5. A high frequency antenna comprising, in combination:

a section of hollow rectangular waveguide supportive of electromagnetic wave energy over a given range of frequencies, said waveguide having a plurality of elongated slots disposed in a wall thereof and electromagnetically coupled thereto;

a loop of conductive wire conductively connected across the longer sides of each of said slots, at least a substantial portion of each of said loops being disposed in a plane substantially parallel to the longer dimension of its corresponding slot; and

means for conductively shorting one end of said waveguide section.

6. A high frequency antenna comprising, in combination:

a section of hollow rectangular waveguide supportive of electromagnetic wave energy over a given range of frequencies, said waveguide having a plurality of elongated slots disposed in a wall thereof and electromagnetically coupled thereto, the longer dimension of each of said slots and the longitudinal spacing between the centers of longitudinally successive ones of said slots being substantially equal to one-half wavelength at the mid-frequency of said range of frequencies; and

a loop of conductive wire conductively connected across the longer sides of each of said slots, at least a substantial portion of each of said loops lying in a plane substantially parallel to said longer dimension of its corresponding slot.

7. An antenna comprising, in combination:

a hollow, conductively bounded, rectangular waveguide

supportive of electromagnetic wave energy over a given range of frequencies in the TE_{10} mode;

a plurality of substantially identical elongated slots longitudinally disposed in a broad wall of said waveguide, alternate slots being disposed on opposite sides of the center line of said broad wall, the longer dimension of each of said slots being substantially parallel to said center line, the longitudinal spacing between the centers of successive slots being substantially equal to one-half wavelength at essentially the mid-frequency of said range of frequencies; and

a loop of conductive wire conductively connected across the longer sides of each of said slots, at least a substantial portion of each of said loops lying in a plane substantially parallel to said center line.

8. In a high frequency antenna of the class having individual radiating elements in the form of elongated slots disposed in a conductive wall of a waveguiding structure, means for achieving an elliptically polarized radiation pattern, said means comprising a loop of conductive wire conductively connected across each of said slots, at least a substantial portion of each of said loops lying in a plane substantially parallel to the longer dimension of its associated slot.

9. A high frequency antenna comprising, in combination:

a thin wafer of conductive material defining an elongated slot;

a thin elongated conductive member in the form of a loop connected between opposite longer sides of said slot on one side of said wafer;

a two-conductor high frequency transmission line feed;

means for conductively connecting one end of each of said conductors to one of said longer sides of said slot; and

means for surrounding said slot on the other side of said wafer with a conductive enclosure.

10. A planar array antenna comprising, in combination:

a plurality of hollow conductively bounded rectangular waveguide sections, adjacent narrow walls of said waveguide sections being contiguously disposed;

feed means electromagnetically coupled to each of said waveguide sections;

a plurality of elongated slots disposed in one of the broad walls of each of said waveguide sections; and

a thin elongated conductive member in the form of a loop connected between opposite longer walls of each of said slots, at least a substantial portion of each of said loops being disposed in a plane substantially parallel to the longer dimension of its corresponding slot.

No references cited.

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