# United States Patent [19]

**Young**

[11] **3,829,862**

[45] **Aug. 13, 1974**


[54] **RIDGE SCAN ANTENNA**


[76] Inventor: **David W. Young,** 627 N. Beechwood Dr., Burbank, Calif. 91506



[22] Filed: **Apr. 20, 1973**

[21] Appl. No.: **353,201**

[52] **U.S. Cl.**..... **343/767,** 343/768, 343/771, 343/778, 343/854

[51] **Int. Cl.**..... **H01q 3/36,** H01q 13/20

[58] **Field of Search**..... 343/768, 770, 771–772, 343/767, 708, 778, 854, 746



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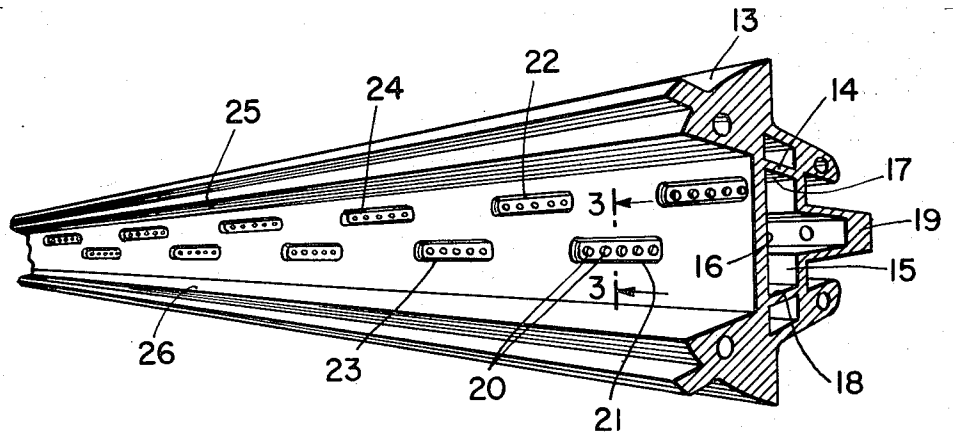
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*Attorney, Agent, or Firm*—Pastoriza & Kelly



[57] **ABSTRACT**

An elongated horizontally disposed waveguide has a series of holes in one longitudinal side wall dimensioned below cut-off so as to be non-resonant and insensitive to wave length variations. The dimensioning and spacing of the holes on the one longitudinal side wall provides for radiation of a fan shaped beam in a vertical plane having a fairly broad elevational angle and an extremely narrow azimuth angle. The fan shaped beam itself is caused to scan through a given angle in azimuth by means of a ridge member reciprocated wholly within a new waveguide structure T shaped in cross section. In addition to the unique waveguide shape and hole design for coupling energy from the waveguide, novel input and output transition structures are provided. The waveguide is typically used in the leading edge of an aircraft wing as a radar antenna.


**24 Claims, 18 Drawing Figures**



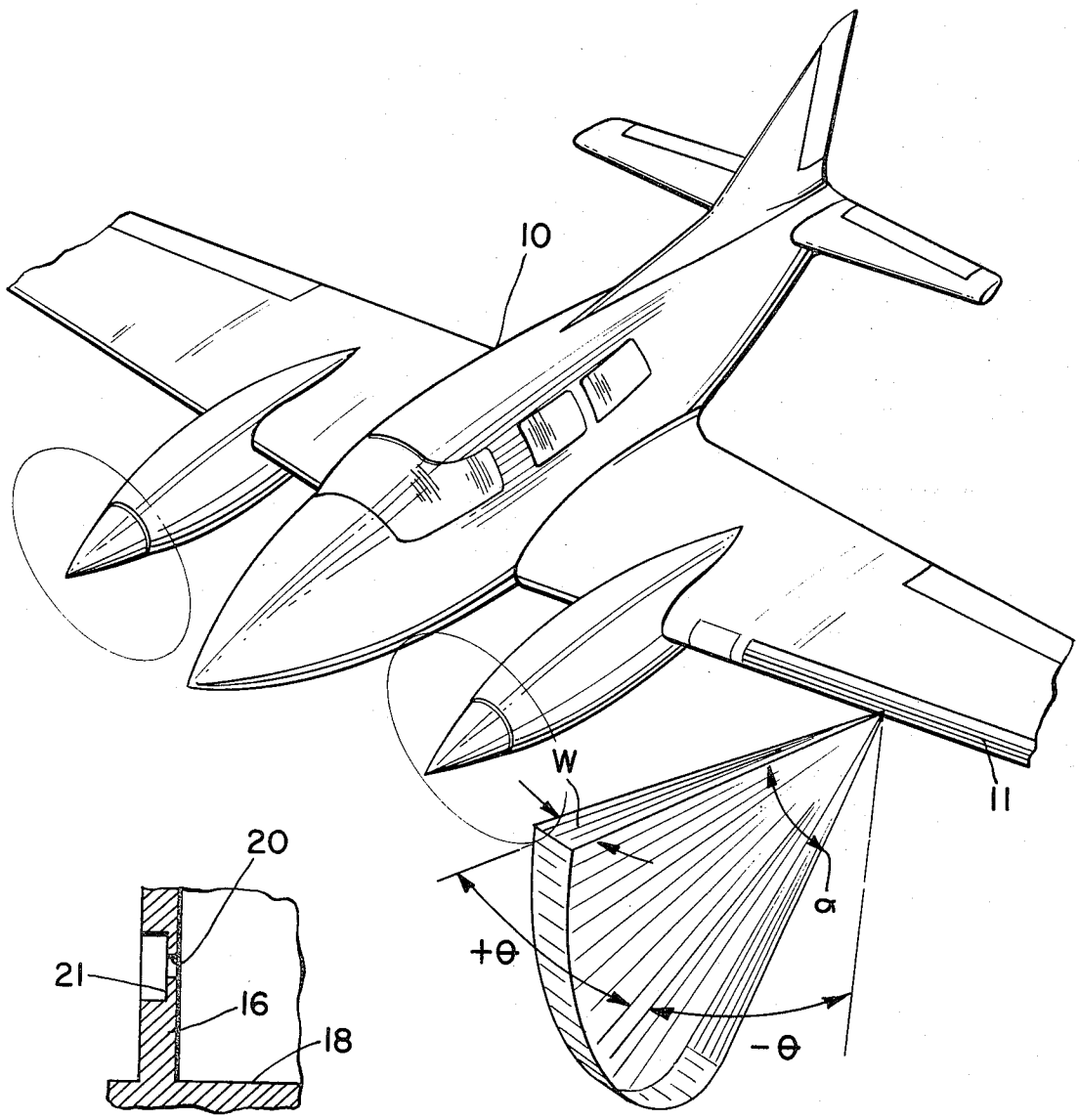



FIG. 1.




FIG. 3.

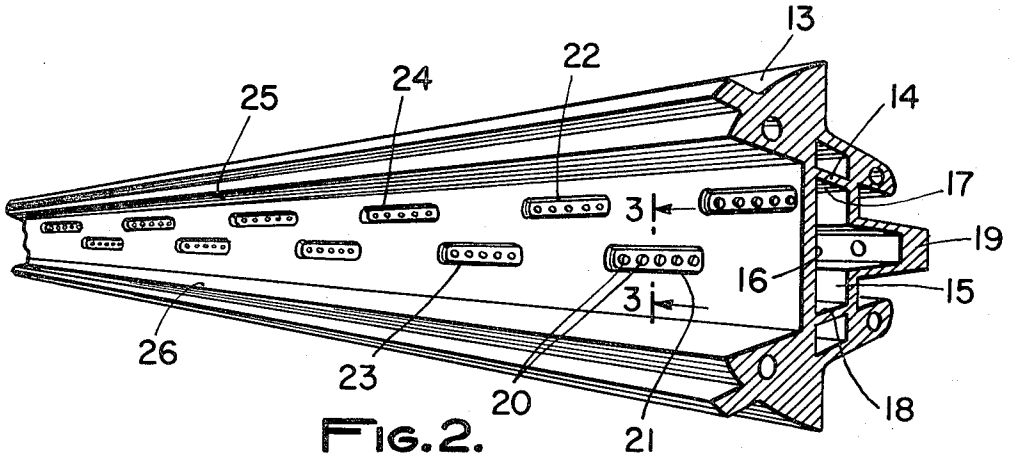



FIG. 2.

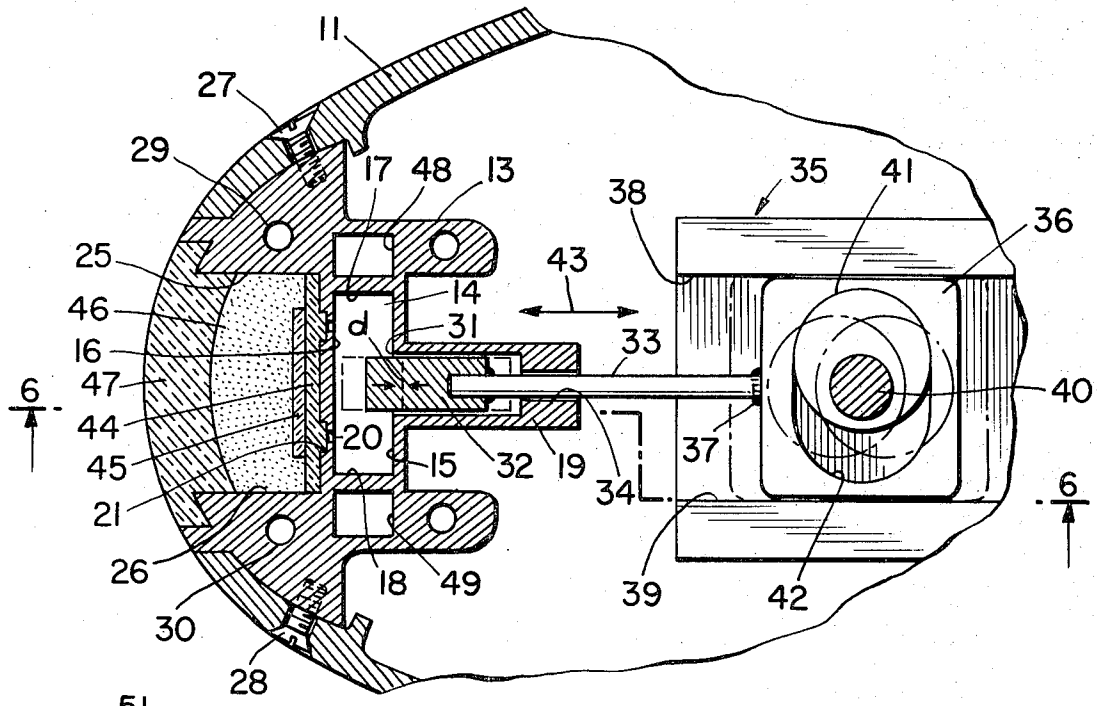



FIG. 4.

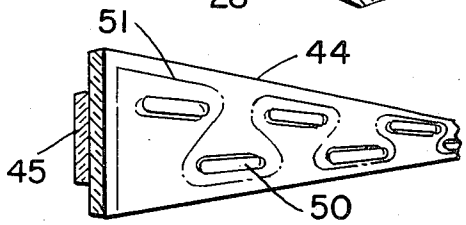



FIG. 5.

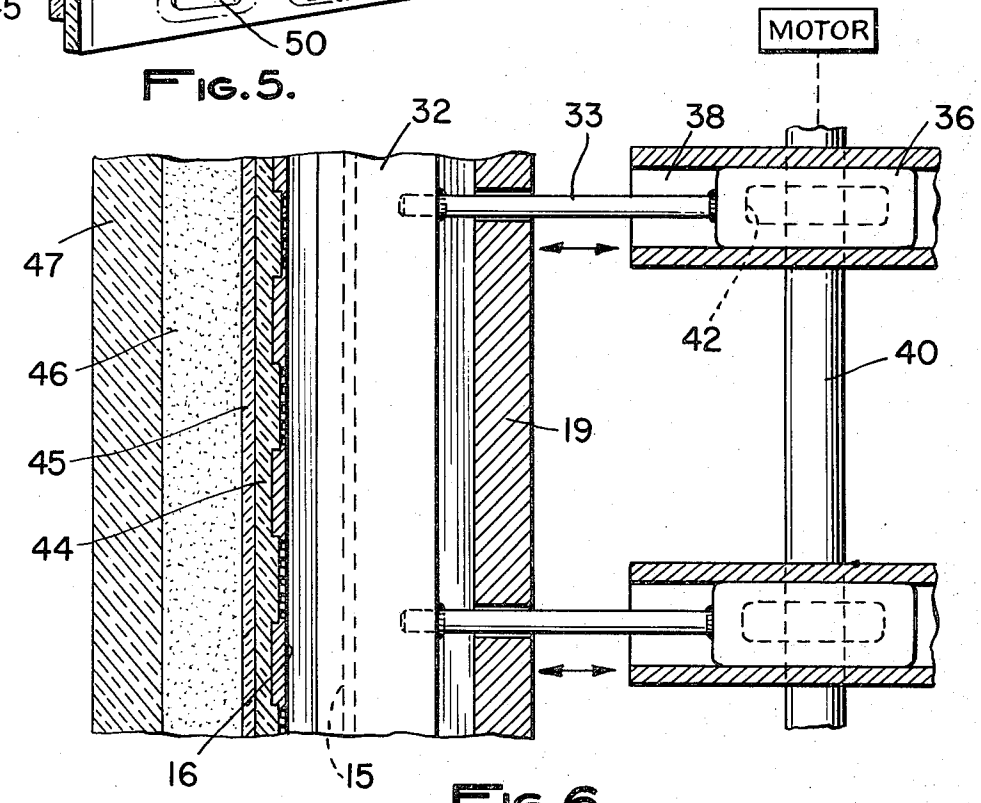



FIG. 6.

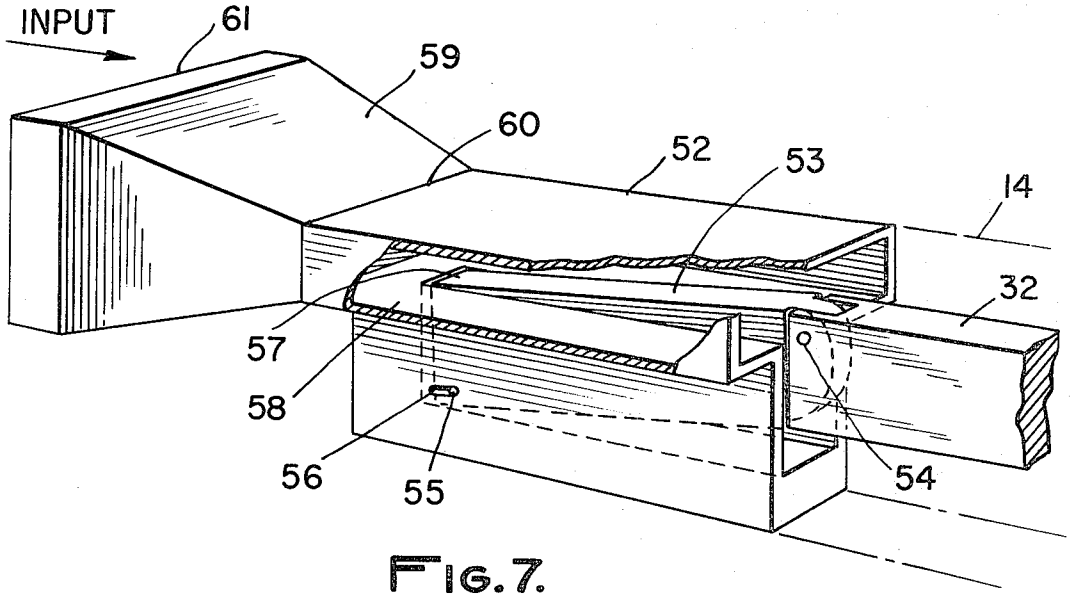



FIG. 7.

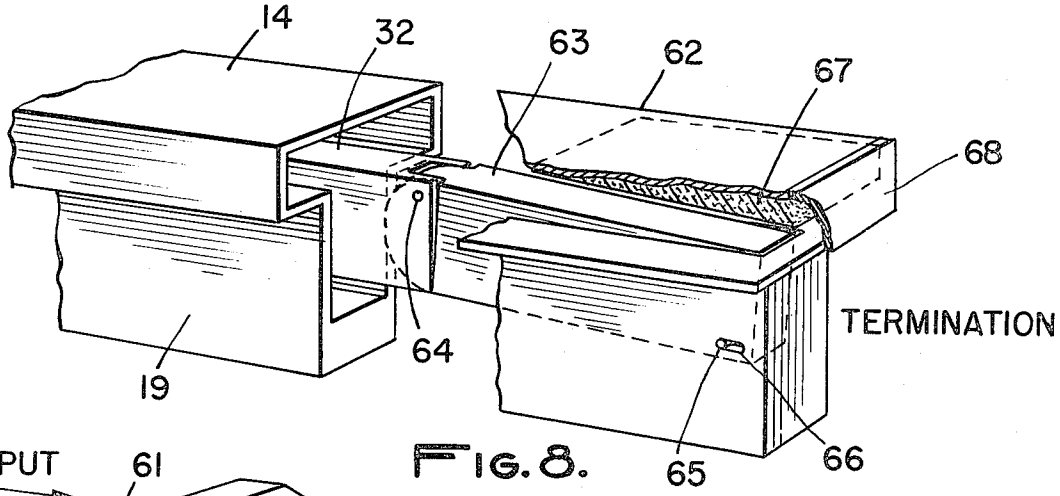



FIG. 8.

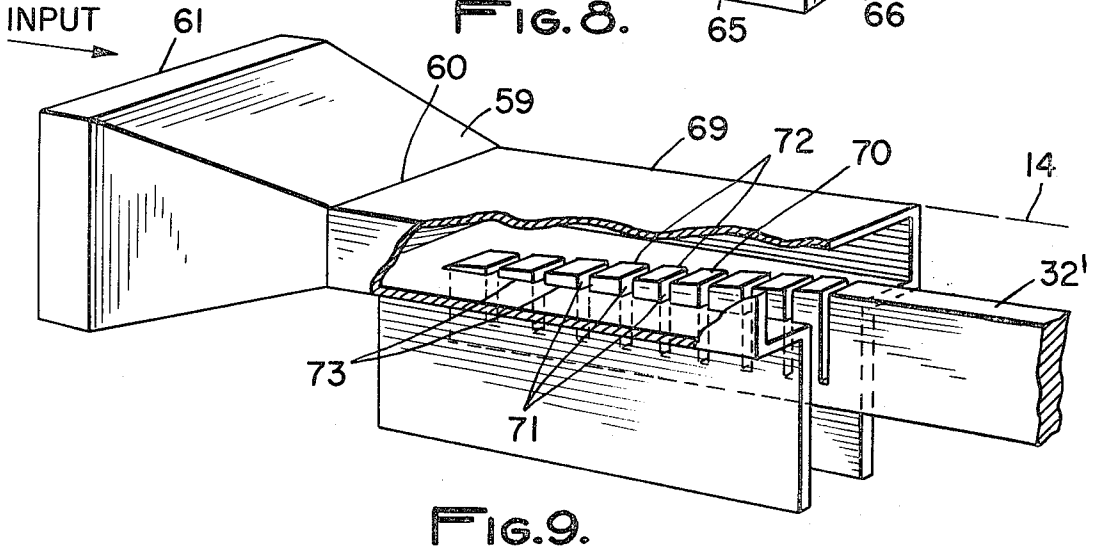



FIG. 9.

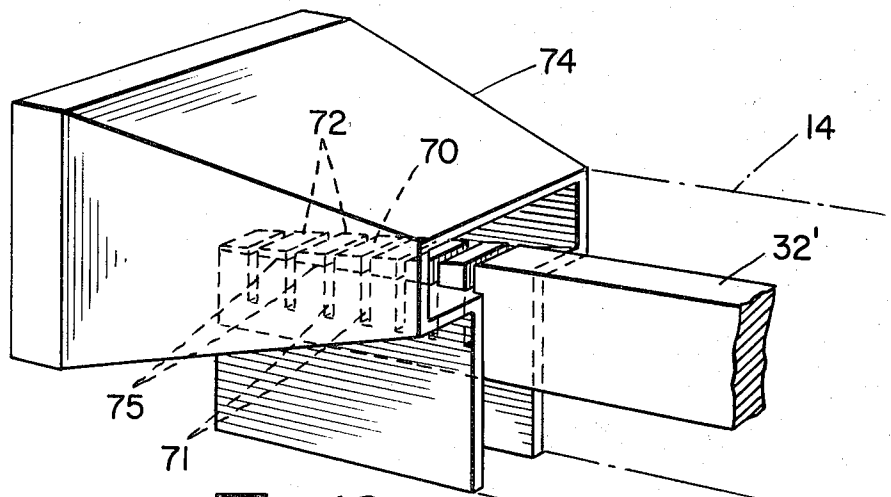



FIG. 10.

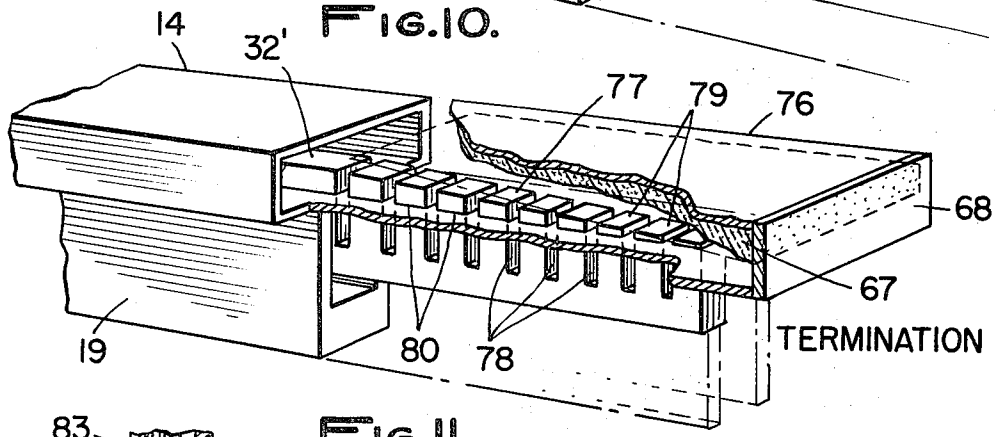



FIG. 11.

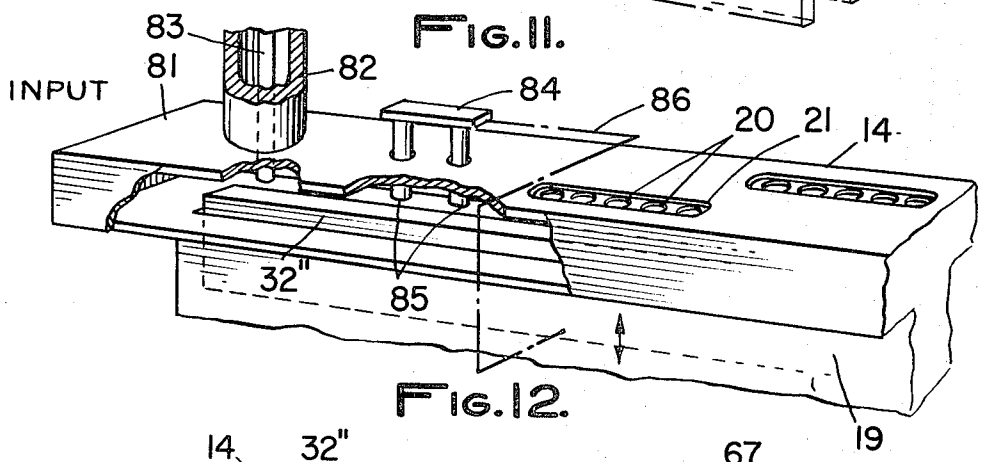



FIG. 12.

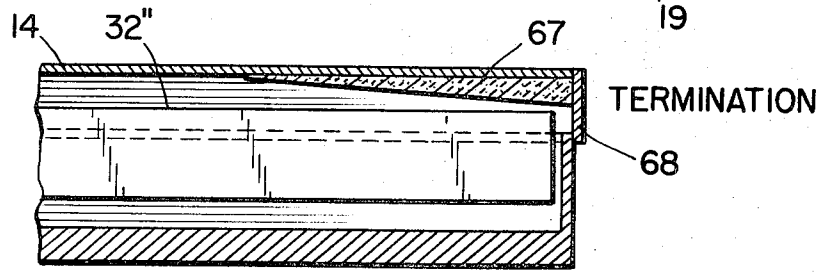



FIG. 13.

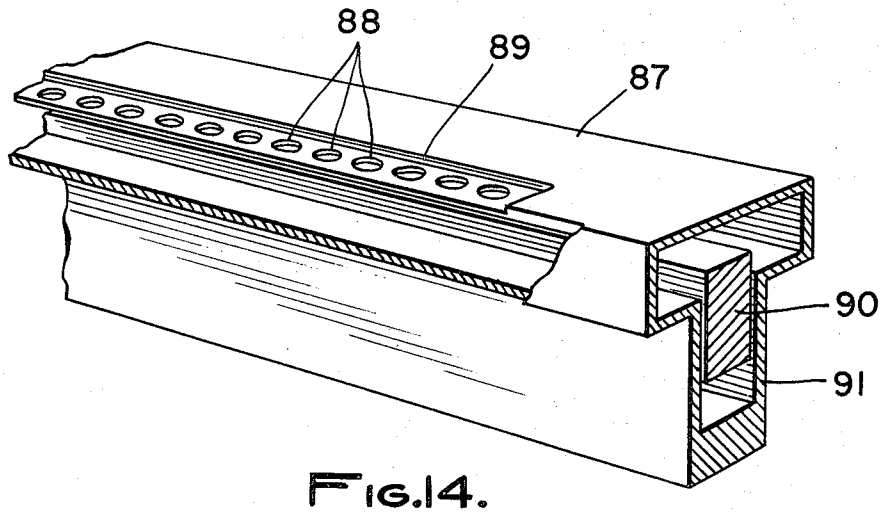



FIG. 14.

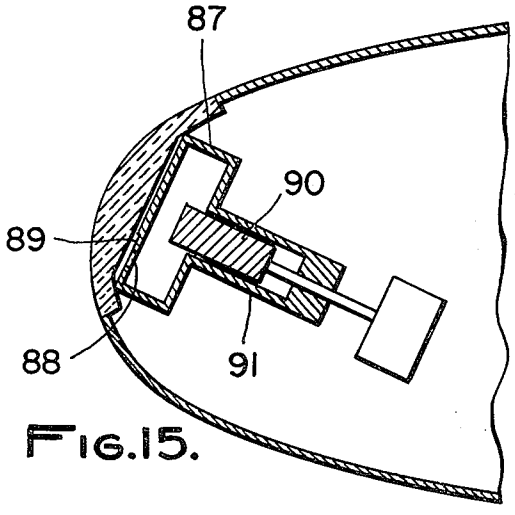



FIG. 15.

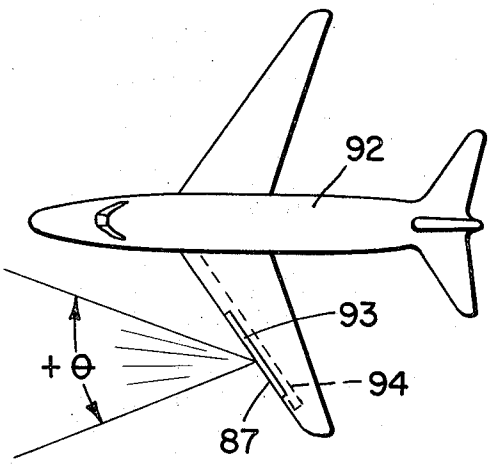



FIG. 16.

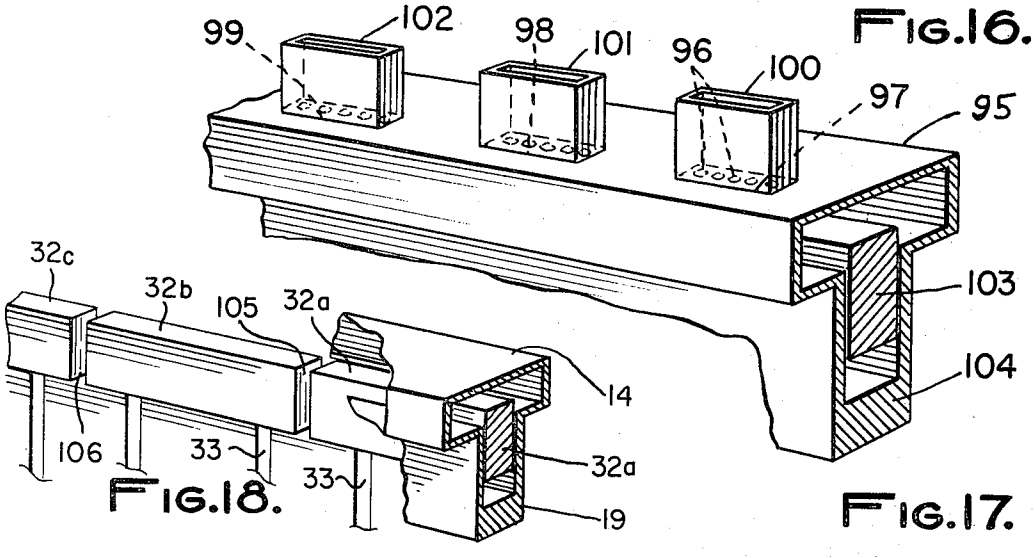



FIG. 18.

FIG. 17.

# RIDGE SCAN ANTENNA

This invention relates generally to radar antenna systems and more particularly to an elongated waveguide type antenna utilizing electro-mechanical elements for effecting scanning of the antenna beam.

## BACKGROUND OF THE INVENTION

In my U.S. Pat. No. 3,389,393 entitled LOW PROFILE BROAD BAND MICROWAVE ANTENNA SYSTEM issued June 18, 1968 there is disclosed a unique waveguide radar antenna preferably for use in helicopter blades wherein an extremely narrow beam which is fan shaped in a vertical plane is generated. The rotation of the helicopter blades themselves effects a desired scanning operation when the antenna is used in conjunction with a helicopter. In this respect, there are avoided some of the electro-mechanical difficulties associated with prior waveguide antennas designed to scan the radiated beam; for example, the well known "eagle scanner." The "eagle scanner" as well as other prior art waveguide scanners which relied on a shifting of the phase velocity of radiation propagated through the guide to provide a scanning pattern, normally utilized resonant slots or openings in the waveguide wall constituting a series of antenna elements for coupling radiation out of the guide to form the desired beam. The basic problem involved is the fact that with such coupling out methods, the shape or geometry of the beam became deteriorated for different scanned positions.

The provision of a series of small closely spaced holes along a longitudinal edge of a waveguide wall such as disclosed in my heretofore referred to U.S. Pat. No. 3,389,393 wherein the holes are dimensioned below cut-off so as to be non-resonant results in a unique step forward in the art in that the phase velocity of radiation can be changed along the waveguide without affecting the desired radiation beam pattern. Such an antenna would be very useful when incorporated in the leading edge of an aircraft wing if some type of means could be provided for scanning the particular beam configuration afforded by the closely spaced non-resonant holes. While scanning of a radiated beam from an elongated waveguide has been effected in the past by altering the phase velocity of radiation through the guide by mechanically changing the effective electrical dimensions of the waveguide walls, it has not been possible to effect a uniform scanning through broadside, that is, a scanning beam which does not suffer from large gain variations.

In my patent application Ser. No. 847,121 filed Aug. 4, 1969, now U.S. Pat. No. 3,778,821, and entitled AIRCRAFT CONTAINED PERSPECTIVE RADAR/-DISPLAY AND GUIDANCE FOR APPROACH AND LANDING, a perspective radar system is shown and described wherein an area of the ground ahead of an aircraft approaching for a landing is scanned by a fan shaped beam and displayed on a radar screen in the cockpit in such a manner as to provide a proper perspective view to the pilot of the outlines of the runway. In this particular radar system, an antenna capable of providing a fan shaped beam in a vertical plane which can be scanned through broadside in azimuth with no appreciable degradation of the beam pattern is most desirable.



While the desired narrow beam pattern in a vertical plane can be achieved by providing a relatively long radiating waveguide, scanning systems for altering the phase velocity of the propagated radiation through the guide in order to effect a proper scanning as known heretofore have not been adequate, particularly for use with the perspective radar system described in my above referred to co-pending application.

## BRIEF DESCRIPTION OF THE PRESENT INVENTION

With the foregoing in mind, the present invention contemplates a radar antenna system for radiating a fan shaped beam in a vertical plane and scanning the beam through a given azimuth angle wherein advantages not heretofore realizable exist. More particularly, one version of the waveguide antenna is designed to effect scanning through broadside and another between broadside and one end, both versions using a rugged and simple mechanical scanning system, the system being insensitive to frequency variations over approximately a frequency octave with respect to the shape of its radiated beam pattern. In addition, the design is such that an extremely low profile structure results permitting installation of the antenna on any elongated surface portion of an aircraft such as the leading edge of an aircraft wing.

Briefly, the antenna system comprises an elongated horizontally disposed waveguide for receiving electromagnetic energy in one end and having a series of holes in one longitudinal side wall dimensioned below cut-off so as to be non-resonant and insensitive to wave length variations, the holes coupling energy out from the waveguide in a manner defining the desired fan shaped beam. To effect scanning, an elongated ridge member essentially co-extensive with the length of the waveguide is positioned within an interior structural portion of the guide along its length. Means are then provided for maintaining the leading edge of the ridge in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from one wall of the waveguide to thereby vary the phase velocity of energy propagated along the waveguide in a manner to effect scanning of said fan shaped beam through said given azimuth angle.

Important features of the invention in various embodiments disclosed relate to the geometry of the cross section of the waveguide and the series of holes. In the embodiment in which scanning is effected through broadside, the series of holes are arranged in first and second groups disposed alternately above and below the longitudinal center line of a longitudinal side wall of the waveguide. The spacing of the groups is such that scanning can take place through broadside. By providing a unique waveguide shape in the form of an extruded T in cross section, the ridge member utilized for effecting the scanning is arranged to essentially "float" in the stem portion of the T and can furthermore assume "negative" positions with respect to conventional rigid ridged waveguide shapes.

Further features have to do with coupling of energy through the holes from the waveguide to free space in an efficient manner and in the provision of unique input and termination transition structures for the waveguide antenna to provide for maximum efficiency in the use of the electromagnetic energy and minimize the overall dimensions of the waveguide.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and further features and advantages of the ridge scan antenna of this invention will be better understood by now referring to the accompanying drawings in which:

FIG. **1** is a fragmentary perspective view of an aircraft incorporating the ridge scan antenna of the present invention in a leading edge of one of the wings;

FIG. **2** is an enlarged fragmentary perspective view of an extrusion forming the elongated waveguide antenna incorporated in the leading edge of the wing in FIG. **1**;

FIG. **3** is a fragmentary cross section taken in the direction of the arrows **3—3** of FIG. **2**;

FIG. **4** is an enlarged fragmentary view partly in cross section showing an end view of the waveguide ridge scan antenna incorporated in the leading edge of the aircraft wing of FIG. **1**;

FIG. **5** is a fragmentary perspective view of dielectric coupling elements associated with the waveguide structure of FIG. **4**;

FIG. **6** is a bottom plan view partly in cross section looking in the direction of the arrows **6—6** of the structure of FIG. **4**;

FIG. **7** is a fragmentary broken away perspective view of an input transition structure for the antenna;

FIG. **8** is a fragmentary broken away perspective view of a termination transition structure for the antenna;

FIG. **9** shows a modified input transition structure;

FIG. **10** shows a modification of the structure of FIG. **9**;

FIG. **11** is a fragmentary broken away perspective view of a modified termination transition for the antenna;

FIG. **12** shows yet another embodiment of an input means for feeding energy into the antenna;

FIG. **13** is a cross section of a termination for use with the input shown in FIG. **12**;

FIG. **14** is a fragmentary perspective view partly broken away of a modified hole arrangement in the antenna of the present invention;

FIG. **15** is an end view of the antenna partially in cross section showing its position in the leading edge of an aircraft wing;

FIG. **16** is a plan view of an aircraft incorporating the antenna of FIG. **15** in its wing;

FIG. **17** is a fragmentary perspective view showing fixed phase shift means associated with an embodiment of the antenna of the invention; and,

FIG. **18** is a fragmentary perspective partly broken away showing a segmented ridge structure for the antenna.

## DETAILED DESCRIPTION OF THE INVENTION

Referring first to FIG. **1** there is shown an aircraft **10** having a leading edge wing portion **11** incorporating the ridge scan antenna of the present invention. This leading edge **11** includes an elongated aperture extending in a horizontal direction and visible from a front line of sight parallel to the axis of the aircraft. The radiated beam is fan shaped in a vertical plane as indicated at **12** and is fairly broad in elevation as indicated by the angle $\alpha$. The width of this fan shaped beam indicated at W is extremely small and is normally determined by the overall length of the elongated waveguide antenna itself in the wing portion **11**. For the particular waveguide antenna to be described, scanning of the fan shaped beam **12** can take place through broadside; that is, through a given azimuth angle $\theta$ on either side of a plane perpendicularly bisecting the antenna.

Typically, the elongated waveguide behind the aperture **11** may be of the order of 102 inches to provide a beam width W of 0.7°. The elevational angle $\alpha$ of the fan shaped beam may be 25° and the azimuth scan angle on either side of broadside indicated at $\theta$ may typically be $\pm$ 15°.

Referring now to FIG. **2**, in accord with an important feature of this invention, the entire waveguide antenna may constitute an aluminum extrusion **13**, the waveguide housing portion being T shaped as indicated at **14** with two opposite longitudinal broad side walls **15** and **16** and two opposite longitudinal narrow side walls **17** and **18** making up the cross of the T and a portion **19** making up the stem of the T.

In the embodiment shown in FIG. **2**, one longitudinal side wall of the waveguide shown as the broad side wall **16** includes a series of holes **20** arranged in first and second groups disposed alternately above and below the longitudinal center line of the side wall. Each of the groups is formed in a recessed area to define a reduced thickness portion surrounding a given number of holes making up the group. The recessed areas for the various groups are shown at **21, 22, 23, 24**, and so forth.

The given number of holes in each group are closely spaced in side by side relation along a given longitudinal distance to define a given length for the group. As shown in FIG. **2**, the spacing between successive groups is of the same order as the given length of any one group.

The small holes making up each group are dimensioned below cut-off so as to be non-resonant and when arranged in the configuration shown in FIG. **2**, energy is coupled out of the waveguide in such a manner that the given azimuth angle of scan passes through broadside.

FIG. **3** shows in fragmentary cross section a detail of the holes **20** and recessed area **21** providing the reduced wall thickness for coupling energy from the guide. Since the diameters of the holes cause them to be beyond cut-off in the region of the operating frequency, theoretically the holes are so small as to act as small round waveguides operated at cut-off which do not propagate but exhibit stable high loss per inch in the cut-off region. Nevertheless and what constitutes a non-obvious and important discovery, is the fact that the waveguide functions as a radiative waveguide, the cross section, reduced wall thickness (typically 010 inches) and distribution of the holes being such as to provide the desired coupling and radiation beam pattern of extremely narrow width in a direction parallel to the axis of the waveguide and fairly broad in elevation. The reduced wall thickness to substantially less than one inch greatly reduces the "loss per inch" factor.

Referring again to FIG. **2**, increased efficiency in coupling energy from the waveguide through the holes and combining the energy from lower and upper hole groups is achieved by providing integral upper and lower longitudinal flanges **25** and **26** extending forwardly from the upper and lower edges of the longitudinal broad side wall **16** to define extended conductive

surfaces guiding the coupled out radiant energy in a forward direction. These flanges as shown may constitute part of the overall extrusion and further serve as a securing means for mounting the waveguide in the leading edge of the wing.

The concept of providing a complete extrusion significantly minimizes any leakage of electromagnetic energy in portions of the waveguide other than the holes.

Referring now to FIG. **4**, the manner in which the extrusion of FIG. **3** is disposed in the leading edge **11** of the wing of the aircraft in FIG. **1** will become evident. As shown, there may be provided simple screws **27** and **28** securing the extended portions making up the flanges **25** and **26** to the leading edge portions of the wing. Further openings such as indicated at **29** and **30** may be provided for receiving suitable mounting means at the end portions of the elongated waveguide.

In addition to the extruded member **13** itself making up the waveguide, there is shown in FIG. **4** a means for scanning the resulting fan shaped beam in accord with the present invention. In this respect, it will be noted that the housing **19** forming the stem of the T-shaped extrusion portion of the guide intercepts the broad side wall **15** to define an open elongated slot **31.** An elongated ridge member **32** coextensive with the length of the radiating portion of the waveguide is arranged to remain in the interior of the guide with a portion partially in slot **31.** Means are then provided for maintaining the leading edge of the ridge **32** in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from the opposite side wall **16** to thereby vary the phase velocity of energy propagated along the waveguide in a manner to effect scanning of the fan shaped beam through the given azimuth angle.

The foregoing means for moving the ridge member includes a series of rods one of which is indicated at **33** rigidly secured at first ends to the trailing edge of the ridge member at evenly spaced longitudinal points, the other ends of the rods passing through bearing openings **34** in the housing **19** to be coupled to a driving means designated generally by the number **35.**

In the particular embodiment shown in FIG. **4**, the driving means **35** includes a reciprocating yoke member **36** to which the extending ends of the rods **33** are secured as at **37.** The yoke **36** reciprocates in guide walls or tracks **38** and **39** by action of a rotating shaft **40** having an eccentric disk **41** within an oblong opening **42** of the yoke **36.** From the dotted line designations, it will be appreciated that when the shaft **40** is rotated by any suitable motor means, the eccentric cam **41** will essentially drive the yoke **36** back and forth between the walls **38** and **39** to thereby move the rods **33** and ridge member **32** in a back and forth motion.

An important feature of this ridge construction resides in the fact that the ridge member **32** itself and rods are held out of physical contact with the housing of the waveguide other than at the points where the rods pass through the bearings **19** so that the ridge is essentially "floating." No chokes are required to concentrate the energy between the ridge and broad wall **16** when the proper transition is used to assure a pure mode.

A further important feature is the fact that the housing **19** which forms the stem of the T shaped waveguide is sufficiently long that the ridge can move freely to a "negative" ridge position with respect to a conventional rigid ridged waveguide shape. Thus, as indicated by the small letter "*d*" the leading edge of the ridge **32** actually moves beyond the slot **31** to be outside of a conventional rigid ridged waveguide shape. The "negative" ridge feature provides for a greater range of phase shift of the velocity of the propagated radiation down the guide to thereby increase the azimuth scanning angle. The reciprocation of the rods **33** and ridge **32** to move the leading edge of the ridge member towards and away from the opposite broad side wall **16** of the waveguide is indicated by the double headed arrow **43.**

Referring now to the front portion of the side wall **16** between the conducting flange surfaces **25** and **26** through which radiation is coupled from the guide, there is shown an elongated plastic means in the form of a strip **44** and a secondary backing plastic strip **45** having dielectric constants of typically 2.0 and 4.0 to effect an optimum coupling of the energy passing from the holes in the waveguide to free space. The area in front of the strips may be filled with foam **46** and a suitable fiberglass radome **47** provided between the front exit portions of the flanges **25** and **26** contoured aerodynamically to conform with the leading edge of the wing **11.**

In the end view of the extrusion **13** of FIG. **4**, there are provided longitudinally extending lightening passages **48** and **49** parallel to and on either side of the narrow sides or walls **17** and **18** of the waveguide **14.** Advantage may be taken of these or similar passages for de-icing purposes by simply passing hot air through the passages to heat the extrusion.

Referring to FIG. **5**, the dielectric plastic strips **44** and **45** are shown in perspective wherein it will be noted that the strip portion **44** includes on its face forward projecting ridges **50** which fit in the recessed areas such as the area **21** of FIG. **4** provided for the holes **20.** In this respect, it is important that the plastic be in surface contact with the exit peripheral portions of the holes to effect the desired coupling of the energy to free space. These same plastic strips can also serve a further function in the event de-icing is desired but wherein lightening passages such as **48** and **49** described in FIG. **4** are not available or are not used. This alternate de-icing system comprises the provision of a conductive path **51** on the front face of the plastic strip **44** following a circuitous route to pass between the ridge portions filling the recessed areas on either side of a center line from one end of the plastic strip towards the other. Current can be passed through the conductive path to thereby heat the extrusion and again serve as a de-icing means.

FIG. **6** shows in bottom plan and in partial cross section the various components described in FIG. **4.** In this FIGURE there is schematically indicated a motor coupled to rotate the shaft **40** and thus effect simultaneous reciprocation of the various rods **33** to move the ridge **32** towards and away from the opposite waveguide wall **16.** The reciprocating motion of the ridge by the means shown in FIGS. **4** and **5** assuming that the motor of FIG. **5** rotates at a constant speed would be sinusoidal so that scanning of the fan shaped beam back and forth between the azimuth angle limits would be sinusoidal. Pure sinusoidal scanning will minimize the generation of mechanical harmonics. On the other hand, there is some dwell time of the scanning beam at the limits of

the scan where it reverses direction. Further if a strictly sinusoidal scan is provided, the motion of the scanning beam is non-linear from one extreme to the other. With the arrangement shown in FIGS. **4** and **5**, the non-linearity throughout the scanning sweep can be corrected by simply providing a motor which does not rotate at a constant speed but rather rotates the shaft **40** with a varying speed in such a manner that the rods **33** and ridge **32** move in their back and forth directions at a constant speed. Such variable speed motors such as stepper type motors are readily available and it is accordingly to be understood that the driving means motor depicted in FIG. **5** could be a variable speed motor thereby providing means for reciprocating the rods to follow a linear motion over a major portion of their travel in each direction.

Another means of effecting linear travel would be to reshape the eccentric shaped cam **41** in such a manner that when the shaft **40** is rotated at a constant speed, the shaping of the cam will urge the yoke **36** and rods **33** in back and forth motion which constitutes over a major portion of the travel in each direction a linear motion.

Referring now to FIG. **7**, there is shown an input energy transition structure for passing electromagnetic energy into one end of the waveguide **14.** This input transition structure includes an input waveguide section **52** having a transition ridge section **53** pivoted at one end as at **54** to the coextensive end of the ridge member **32** in the waveguide **14.** The other end of the transition ridge section **53** in turn is coupled as by a pivot pin **55** which can ride in a slot **56** in such a manner that the top end surface **57** of the ridge section is generally flush with the wall **58** through which the ridge extends.

With the foregoing arrangement, a gradual diminution of the effect of the ridge member is provided for any given position of the ridge member for the electromagnetic energy passing into the main waveguide **14.**

In addition, the input energy transition structure shown includes an expanding waveguide coupling section **59** with its convering end coupled to the input waveguide section as at **60** and its expanded end **61** properly dimensioned to receive input electromagnetic energy carried in a standard sized waveguide for the particular operating frequency.

To minimize reflections at the other end of the elongated waveguide, a similar termination transition structure is provided. Thus, referring to FIG. **8** there is shown a termination waveguide section **62** having a transition ridge section **63** pivoted at **64** to the end of the ridge member coextensive with the other end of the waveguide **14.** The other end of the termination transition ridge section is coupled as by pivot pin **65** and cooperating slot **66** in such a manner that its top surface will be flush with the wall of the termination waveguide section so that again a gradual diminution of the effect of the ridge member is provided for any given position of the ridge member. This termination structure also includes a wedge shaped section of ferrite material **67** on the wall of the termination waveguide section **62** opposite to the transition ridge section to minimize reflections of energy, the waveguide section **62** itself being closed at its extreme end as by a metal plate **68.**

FIGS. **9, 10,** and **11** illustrate alternative input and termination transition structures to those described in FIGS. **7** and **8.**

Considering first the input transition structure shown in FIG. **9,** there is provided an input waveguide section **69** within which there is an integral extension of the ridge member **32** for the main waveguide **14,** this ridge member being designated **32'** in FIG. **9.** The integral extension of the ridge member is shown at **70,** its upper edge tapering towards its lower edge and including a plurality of slots **71** to define ridge projections **72** decreasing successively in height. The floor of the input waveguide section **69** in turn includes a series of windows **73** or openings through which the ridge projections **72** extend when the ridge member is moved into and out of the waveguide. The effect of this arrangement is to provide a gradual diminution of the effect of the ridge member for any given position of the ridge member and has the advantage of avoiding relatively moving ridge section parts such as is the case with the pivoted structure of FIG. **7.** In the input transition structure of FIG. **9** there is again provided an expanding waveguide coupling section **59** with its converging end connected at **60** to the input waveguide section **69** and its expanded end **61** receiving input electromagnetic energy. Since this expanding waveguide section is identical to that shown in FIG. **7,** the same numerals have been used.

In order to minimize the overall length of the antenna, the input waveguide section **69** itself may constitute an expanding waveguide section.

FIG. **10** shows such an expanding waveguide section at **74** wherein the expanding lower wall includes a series of windows **75** for receiving the ridge projections **72** of the tapered integral ridge **70.**

FIG. **11** illustrates a termination transition structure utilizing a slotted tapered transition ridge in place of the pivoted ridge section described in FIG. **8.** Thus, the termination waveguide section is shown at **76** having an integral tapered ridge section **77** slotted at **78** to define ridge projections **79** passing up through a series of windows **80** in the termination section **76.** A wedge shaped section of ferrite **67** and metallic closure end plate **68** is provided for the termination waveguide **76,** these latter elements being identical to the wedge section and closure plate **67** and **68** described in FIG. **8.**

Further shortening of the overall length of the waveguide antenna can be accomplished by eliminating transition structures such as described in the previous drawings and feeding electromagnetic energy into the main waveguide by a coaxial line. Such an input structure is illustrated in FIG. **12** wherein the one end of the main waveguide **14** to receive electromagnetic energy includes an input waveguide section **81** having a ridge section designated **32''** which constitutes an integral part of the ridge member **32** in the main wave guide **14.** The upper wall of the waveguide section **81** opposite the ridge portion **32''** has a coaxial line comprised of an outer conductor **82** terminating at the wall of the waveguide **81** and an inner conductor **83** extending into the waveguide towards the top edge of the ridge section **32''.** This inner conductor **83** terminates short of the leading edge of the ridge section.

In order that input electromagnetic energy in the coaxial line is transferred to the waveguide with maximum coupling efficiency for every position of the ridge member, it is necessary to provide a movable tuning

probe means extending into the wall of the waveguide section which in the example shown in located at **84** between the inner conductor **83** and the remaining elongated portion of the waveguide **14.** This tuning probe means may take the form of a probe structure having two spaced probes **85** extending into the waveguide parallel to the inner conductor **83** of the coaxial line. The probes **85** are caused to move in and out of the waveguide in synchronism with movement of the ridge, any suitable mechanical connection **86** between the probe structure **84** and the ridge **32** accomplishing this desired result. The use of the probes is intended to follow well known theory in the use of tuning screws to minimize the voltage standing wave ratio.

By utilizing a coaxial input for the waveguide, it will be appreciated that space taken up by the heretofore described transition section is eliminated.

FIG. **13** illustrates a termination arrangement which might be utilized with the input in any of FIGS. **7, 9, 10** or **12** to shorten the other end of the waveguide. In FIG. **13,** the far end of the main waveguide **14** is simply terminated by a metallic plate **68** corresponding to the plates **68** described in FIGS. **8** and **11.** In addition, there is provided the wedge shaped section **67** of ferrite material to minimize reflections, the ridge member **32''** constituting an integral extension of the main ridge member **32** in the waveguide **14.**

Referring now to FIG. **14,** there is shown a modified waveguide antenna **87** wherein a series of holes dimensioned below cut-off so as to be non-resonant extend longitudinally between the longitudinal edge of the broad side wall of the waveguide. As shown, the portion of the wall through which the holes extend is recessed as at **89** to provide a reduced thickness portion as in the case of the series of holes formed in groups described with respect to the waveguide antenna **14** in FIGS. **2** and **4.** However, as in the case of the antenna **14** there is provided a scanning ridge member **90** within an extending housing **91** so that the same general T shape configuration results. The ridge **90** is driven in the same manner as the ridge **32** described in the previous embodiments and thus details of such drive means are not shown in FIG. **14.**

The configuration of the series of holes in the waveguide **87** of FIG. **14** will not permit scanning of the fan shaped beam through broadside. However, there are many wing configurations in aircraft where such scanning through broadside is not really necessary.

For example, referring to FIG. **15** the positioning of the waveguide antenna **87** in the leading edge portion of a wing is shown. The various portions of the waveguide are designated by the same numerals used in FIG. **14.** When positioned as shown in FIG. **15,** the fan shaped beam will radiate out the front of the leading edge of the wing and when the ridge member **90** is reciprocated, this fan shaped beam will sweep from a near broadside position towards the end of the waveguide opposite the end receiving electromagnetic energy.

The foregoing will be evident from FIG. **16** which illustrates an aircraft **92** having swept back wings wherein the leading edge **93** incorporates the waveguide **87** of FIG. **15.** In this embodiment, to provide the scan in azimuth over the angle $\theta$ as indicated, the waveguide **87** is fed at its far end adjacent the top of the wing as indicated by the dashed line **94.** Even though the fan shaped beam does not scan through broadside, in the case of a swept back wing structure as shown, the azimuth angle covered by the beam covers the desired forward area.

FIG. **17** constitutes a modified waveguide antenna **95** similar to waveguide antenna **87** shown in FIG. **14** but wherein the series of holes are arranged in groups such as indicated at **96** serially extending between the longitudinal center line and one edge of the wall of the guide. Each group comprises a given number of holes in closely spaced side by side relation along a given longitudinal distance to define a given length for the group. This spacing between successive groups is of the same order as this length. In this respect, the waveguide **95** is the same as the waveguide **14** described in FIGS. **2** and **4** except that the groups of holes adjacent the opposite longitudinal edge are not included. The longitudinal wall including the groups has recessed areas such as indicated at **97, 98,** and **99** to provide reduced wall thickness portions surrounding the holes to increase the efficiency of coupling of energy out of the waveguide.

In the waveguide antenna **95,** there is additionally included a fixed phase shift means in the form of waveguide stubs **100, 101,** and **102** surrounding each of the groups of holes and extending normally from the longitudinal wall. As in the case of the other waveguide antennas, there is provided a ridge member **103** within a housing **104** extending from the waveguide **95** in a direction opposite from the wall containing the holes.

The waveguide stubs constitute fixed phase shifters having different electrical lengths such that the angular relationship of the limits of the azimuth angle through which the fan shaped beam is scanned by movement of the ridge member **103,** relative to a vertical plane perpendicularly bisecting the waveguide, can be changed.

The provision of such fixed phase shifters would enable adjustment of the azimuth scan angle limits depicted in FIG. **16** to accommodate different geometries of swept back wings to assure that the fan shaped beam covers the forward ground area on either side of the center line of the aircraft.

In all of the various embodiments described, the elongated ridge member has been shown as a solid bar like structure. When the length of the waveguide antenna is of the order of ten feet, stresses tend to be established in the ridge member in its reciprocating movement. Relief of such stresses can be achieved by segmenting the ridge member into shorter sections to make up an overall long length.

Referring to FIG. **18,** such a segmentation of the ridge member is shown. Thus, for the waveguide **14** there is illustrated segmented ridge member sections **32***a*, **32***b*, **32***c* within the waveguide portion **19.** Suitable severing of the ridge member to define the sections is shown at **105** and **106.** The solid section of the ridge **32***b* between the cuts would be longer than depicted in FIG. **18.**

It will be understood that the gap between the adjacent ridge sections at the cuts **105** and **106** is small with respect to a wave length, the resultant effect being that of a continuous ridge.

This type of ridge member construction could be utilized with the other embodiments heretofore set forth.

It should also be understood that the slots formed in the transition ridge sections heretofore described, are

small compared to a wave length and the windows in the waveguide floor through which the projections of the ridge sections extend are below cut-off. With this arrangement, the bottom wall of the stem portion **19** of the waveguide can be removed as shown in some of the drawings to provide access in the manufacture of the windows in the waveguide transition sections.

What is claimed is:

**1.** A radar antenna system for radiating a fan shaped beam in a vertical plane and scanning the beam through a given azimuth angle, comprising, in combination:

a. an elongated horizontally disposed waveguide for receiving electro-magnetic energy in one end and having a series of holes in one longitudinal side wall dimensional below cut-off so as to be non-resonant, said holes coupling energy out from the waveguide in a manner defining said fan shaped beam, the non resonant characteristic of said holes rendering the shape of said beam substantially insensitive to frequency variations over approximately a frequency octave;

b. an elongated ridge member co-extensive with the length of said waveguide arranged to extend wholly within the guide along its length; and,

c. means for maintaining the leading edge of the ridge in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from the opposite side wall of the waveguide to thereby vary the phase velocity of energy propagated along the waveguide in a manner to effect scanning of said fan shaped beam through said given azimuth angle.

**2.** A radar antenna system for radiating a fan shaped beam in a vertical plane and scanning the beam through a given azimuth angle, comprising, in combination:

a. an elongated horizontally disposed waveguide for receiving electro-magnetic energy in one end and having a series of holes in one longitudinal side wall dimensioned below cut-off so as to be non-resonant, said holes coupling energy out from the waveguide in a manner defining said fan-shaped beam;

b. an elongated ridge member co-extensive with the length of said waveguide arranged to extend wholly within the guide along its length; and,

c. means for maintaining the leading edge of the ridge in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from the opposite side wall of the waveguide to thereby vary the phase velocity of energy propagated along the waveguide in a manner to effect scanning of said fan shaped beam through said given azimuth angle, said series of holes being arranged in first and second groups disposed alternately above and below the longitudinal center line of said one longitudinal side wall, each group comprising a given number of holes in closely spaced side-by-side relation along a given longitudinal distance to define a given length for the group, the spacing between successive groups being of the same order as said given length whereby energy is coupled out of the waveguide in such a manner that said given azimuth angle of scan passes through and on either side of a vertical plane bisecting the waveguide at its mid-point and oriented perpendicularly to the longitudinal axis of the waveguide.

**3.** An antenna according to claim **2,** in which said one longitudinal side wall includes recessed areas to define reduced thickness portions surrounding the given number of holes making up the groups to increase the efficiency of coupling of energy out of the waveguide through the holes.

**4.** An antenna according to claim **3,** in which said elongated waveguide constitutes an integral extrusion in the form of a T in cross section, the stem of the T accomodating at least a portion of said ridge, the broad side wall opposite the ridge constituting said one longitudinal side wall having recessed areas and said series of holes, said extrusion further defining integral upper and lower longitudinal flanges extending forwardly from the upper and lower edges of the said longitudinal side wall to define extended conductive surfaces guiding the coupled out radiant energy in a forward direction and further defining securing means for facilitating the mounting of the waveguide in the leading edge of an aircraft wing, the entire extrusion minimizing any leakage of electromagnetic energy in portions of the waveguide other than the holes.

**5.** An antenna according to claim **4,** including an elongated plastic means extending longitudinally between said upper and lower flanges in surface contact with said one longitudinal side wall, said plastic means including portions filling said recessed areas, the dielectric constant of the plastic means having a value to effect an optimum coupling of the energy passing from the waveguide to free space.

**6.** An antenna according to claim **4,** in which said extrusion further defines longitudinal lightening passages running parallel to and on either exterior side of the narrow sides defined by the rectangular waveguide, whereby when said waveguide is mounted in the leading edge of an aircraft wing, hot air can be passed through said passages to heat said extrusion and serve as a de-icing means for the wing.

**7.** An antenna according to claim **5,** in which said elongated plastic means includes a conductive path following a circuitous route to pass between said portions filling said recessed areas on either side of a center line from one end of the plastic means towards the other such that current can be passed through the conductive path to heat the extrusion and serve as a de-icing means for the wing.

**8.** An antenna according to claim **1,** in which said waveguide is T shaped in cross section, said one longitudinal side wall having the series of holes constituting a broad side wall, said ridge member being positioned in the stem of said T shape for movement towards and away from said broad side wall, said means for maintaining the leading edge of the ridge member in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from the broad side wall, including:

a. a series of rods rigidly secured at first ends to the trailing edge of the ridge member at evenly spaced longitudinal points, the other ends of the rods passing through bearing openings in the stem of the T shape; and

b. a driving means coupled to said other ends of the rods for reciprocating them in unison back and forth in the housing to thereby move the ridge towards and away from said broad side wall, the

ridge member itself and rods being held out of physical contact with the T shaped waveguide other than at the bearing openings so that it is "floating."

**9.** An antenna according to claim **8,** in which the stem of the T shape is sufficiently long that said ridge member can move freely within the stem to a "negative" ridge position with respect to a conventional rigid ridged waveguide shape.

**10.** An antenna according to claim **8,** in which said driving means includes means for reciprocating said rods to follow a linear motion over a major portion of their travel in each direction.

**11.** An antenna according to claim **1,** having an input energy transition structure for passing said electromagnetic energy into said one end of said waveguide, said input transition structure including:

a. an input waveguide section having a transition ridge section pivoted at one end to the co-extensive end of said ridge member in the waveguide, and having its other end coupled to be flush with one wall of said input waveguide section such that a gradual diminution of the effect of the ridge member is provided for any given position of the ridge member; and

b. an expanding waveguide coupling section with its converging end coupled to the input waveguide section, and its expanded end receiving input electromagnetic energy.

**12.** An antenna according to claim **1,** having a termination transition structure for providing a proper termination impedance for energy passing towards the other end of said waveguide, said termination transition structure including:

a. a termination waveguide section having a closed end and a transition ridge section pivoted at one end to the end of the ridge member co-extensive with said other end of the waveguide, and having its other end coupled to be flush with one wall of said termination waveguide section such that a gradual diminution of the effect of the ridge member is provided for any given position of the ridge member; and

b. a wedge-shaped section of ferrite material on the wall of the termination waveguide section opposite to the transition ridge section to minimize reflections of energy at said other end of the waveguide.

**13.** An antenna according to claim **1,** having an input energy transition structure for passing said electromagnetic energy into said one end of said waveguide, said input transition structure including:

an input waveguide section including a transition ridge section constituting an integral extension of the ridge member, said extension having its upper edge tapering towards its lower edge and including a plurality of slots to define ridge projections decreasing successively in height, the floor of said waveguide section including a series of windows through which said ridge projections extend when said ridge member is moving in the waveguide to thereby provide a gradual diminution of the effect of the ridge member for any given position of the ridge member.

**14.** An antenna according to claim **13,** in which said input energy transition structure includes an expanding waveguide coupling section with its converging end connected to said input waveguide section and its expanded end receiving input electromagnetic energy.

**15.** An antenna according to claim **13,** in which said input waveguide section expands in size from its end coupled to the waveguide to its end receiving input electromagnetic energy.

**16.** An antenna according to claim **1,** having a termination transition structure for providing a proper termination impedance for energy passing towards the other end of said waveguide, said termination transition structure including: a termination waveguide section having a closed end and a transition ridge section constituting an integral extension of the ridge member, said extension having its upper edge tapering towards its lower edge and including a plurality of slots to define ridge projections decreasing successively in height, the floor of said termination waveguide section including a series of windows through which said ridge projections extend when said ridge member is moving in the waveguide; and a wedge-shaped section of ferrite material on the wall of the termination waveguide section opposite to the transition ridge section to minimize reflections of energy at said other end of the waveguide.

**17.** An antenna according to claim **1,** having an input structure for passing electromagnetic energy into said one end of said waveguide including:

an input waveguide section including a ridge section constituting an integral extension of said ridge member, the upper wall of the waveguide section opposite said ridge section having a coaxial line connected thereto, the outer conductor of the line terminating at the wall and the inner conductor extending into the waveguide towards the top edge of said ridge section, said inner conductor terminating short of the ridge section; movable tuning probe means extending into said wall of the waveguide section between the inner conductor and the point of connection of the waveguide section to said waveguide; and means mechanically connecting the tuning probe means to said ridge member for movement with the ridge member whereby input electromagnetic energy in said coaxial line is transferred to said waveguide with maximum coupling efficiency for every position of the ridge member.

**18.** An antenna according to claim **1,** having a termination transition structure for providing a proper termination impedance for energy passing towards the other end of said waveguide, said termination transition structure including: a wedge shaped section of ferrite material on the wall of said other end of said waveguide opposite the co-extensive end portion of said ridge member; and a metallic end wall closing the said other end of the waveguide, the wedge shaped section minimizing reflections of energy at said other end of the waveguide.

**19.** A radar antenna system for radiating a fan shaped beam in a vertical plane and scanning the beam through a given azimuth angle, comprising, in combination:

a. an elongated horizontally disposed waveguide for receiving electro-magnetic energy in one end and having a series of holes in one longitudinal side wall dimensioned below cut-off so as to be non-resonant, said holes coupling energy out from the waveguide in a manner defining said fan-shaped beam;

b. an elongated ridge member co-extensive with the length of said waveguide arranged to extend wholly within the guide along its length; and,

c. means for maintaining the leading edge of the ridge in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from the opposite side wall of the waveguide to thereby vary the phase velocity of energy propagated along the waveguide in a manner to effect scanning of said fan shaped beam through said given azimuth angle, said series of holes extending longitudinally between the longitudinal center line and one edge of said one longitudinal wall in closely spaced side-by-side relationship, the portion of the wall through which the holes pass being recessed to provide a reduced thickness portion to increase the efficiency of coupling of energy out of the waveguide.

**20.** A radar antenna system for radiating a fan shaped beam in a vertical plane and scanning the beam through a given azimuth angle, comprising, in combination:

a. an elongated horizontally disposed waveguide for receiving electro-magnetic energy in one end and having a series of holes in one longitudinal side wall dimensioned below cut-off so as to be non-resonant, said holes coupling energy out from the waveguide in a manner defining said fan-shaped beam;

b. an elongated ridge member co-extensive with the length of said waveguide arranged to extend wholly within the guide along its length; and,

c. means for maintaining the leading edge of the ridge in parallel relation with the longitudinal axis of the waveguide while moving the ridge towards and away from the opposite side wall of the waveguide to thereby vary the phase velocity of energy propagated along the waveguide in a manner to effect scanning of said fan shaped beam through said given azimuth angle, said series of holes being arranged in groups serially extending between the longitudinal center line and one edge of said one longitudinal wall, each group comprising a given number of holes in closely spaced side-by-side relation along a given longitudinal distance to define a given length for the group, the spacing between successive groups being of the same order as said given length, the longitudinal wall including recessed areas to define reduced thickness portions surrounding the given number of holes making up the groups to increase the efficiency of coupling of energy out of the waveguide.

**21.** An antenna according to claim **20,** including short waveguide stubs surrounding each of the groups of holes and extending normally from said one longitudinal wall, said waveguide stubs constituting fixed phase shifters having different electrical lengths whereby the angular relationship of the limits of the azimuth angle through which the fan shaped beam is scanned by movement of said ridge member, relative to a vertical plane perpendicularly bisecting the waveguide, can be changed.

**22.** An antenna according to claim **1,** in which said elongated ridge member is periodically segmented to structurally relieve stresses in the ridge member when moved towards and away from said opposite side wall of the waveguide.

**23.** A radar antenna system comprising: an elongated horizontally disposed waveguide for receiving electromagnetic energy in one end and having a series of holes in one longitudinal side wall dimensioned below cut-off so as to be non-resonant and substantially insensitive to wave length, said holes being arranged in first and second groups disposed alternately above and below the longitudinal center line of said one longitudinal side wall, each group comprising a given number of holes in closely spaced side by side relation along a given longitudinal distance to define a given length for the group, the spacing between successive groups being of the same order as said given length whereby energy is coupled out of the waveguide to provide a fan shaped beam lying in a vertical plane including broadside.

**24.** A radar antenna according to claim **23,** in which said waveguide has a T shape in cross section; a ridge member in the stem portion of the T shape; and means for moving the ridge member partially into and completely out of that portion of the waveguide defined by the cross of the T shape, the stem of the T shape being sufficiently long that said ridge member is moved into the stem so that its leading edge is moved below the cross of the T shape to a "negative" ridge position, the movement of the ridge member effecting a scanning of said fan shaped beam, through an azimuth angle on either side of broadside.

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