

March 31, 1959

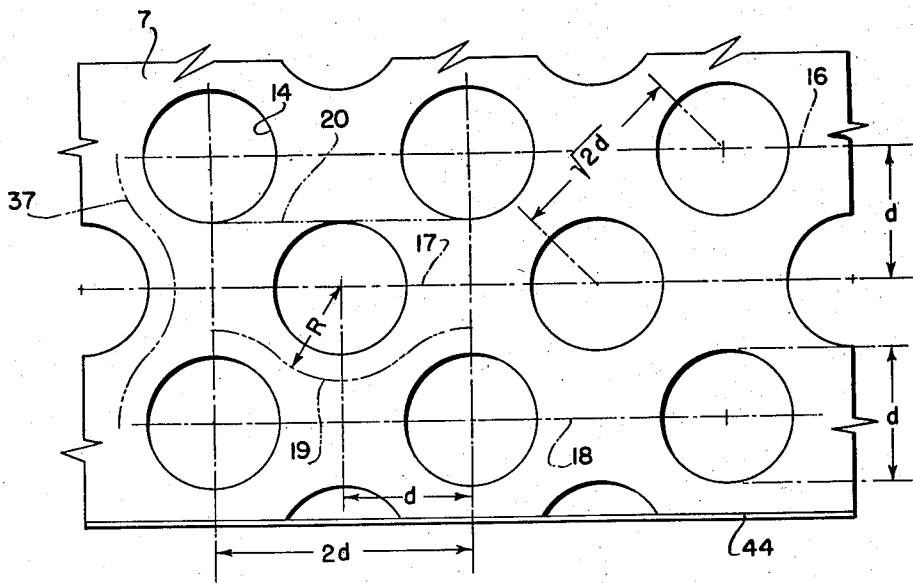
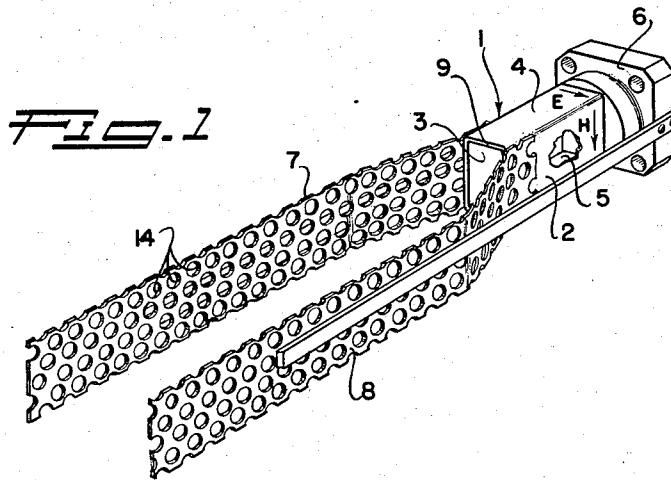
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2,880,417

TRAVELING WAVE DEVICE

Filed Feb. 11, 1955

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

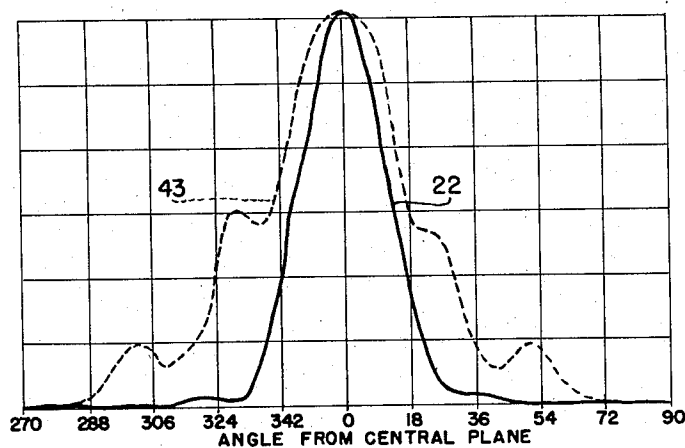


FIG. 7

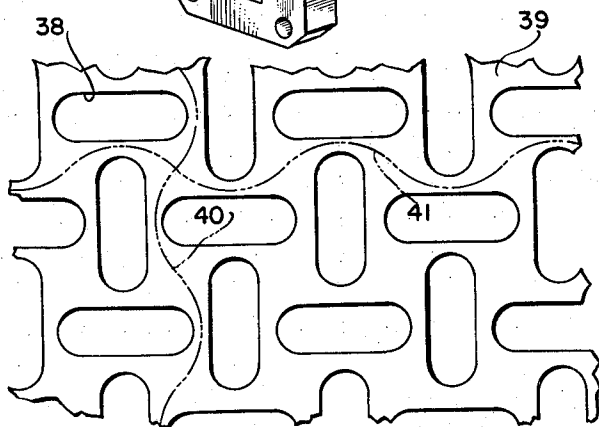
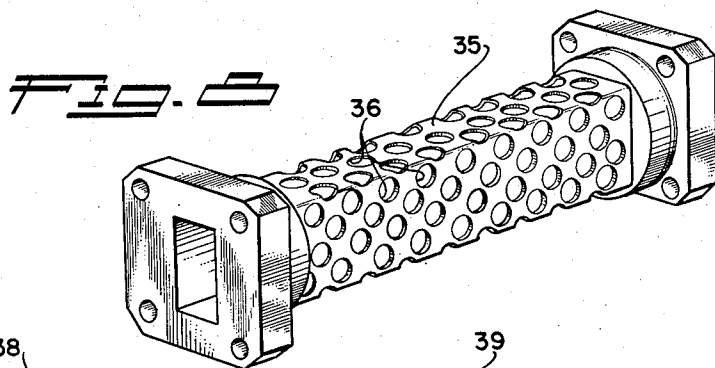


FIG. 8

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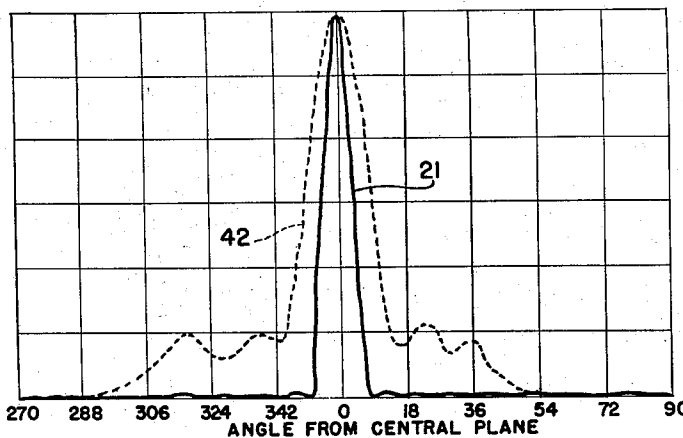
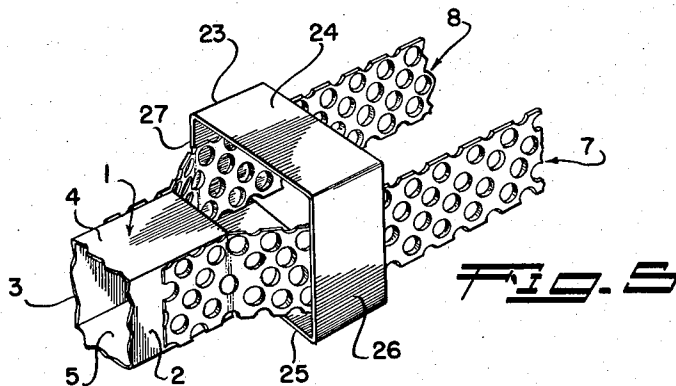
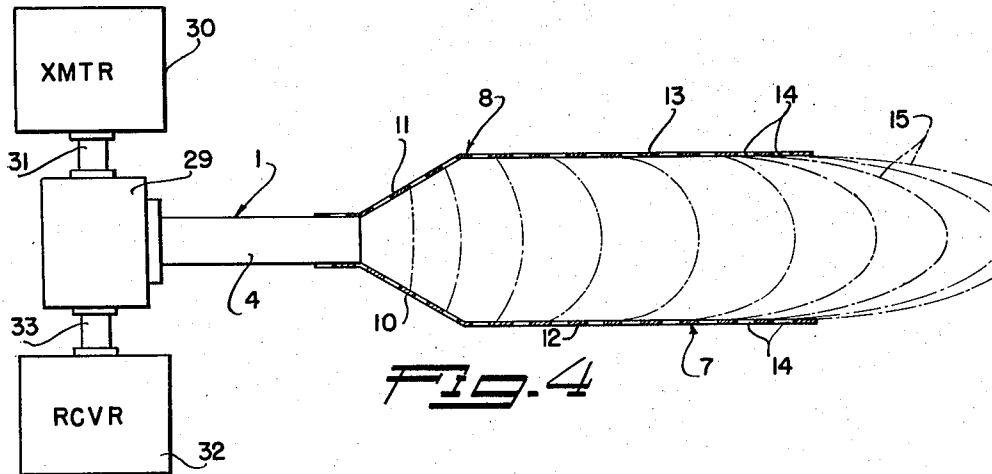
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3 Sheets-Sheet 3



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TRAVELING WAVE DEVICE

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This invention relates, generally, to traveling wave devices and more particularly to a light-weight and highly directive retarded wave antenna having means for delaying an electromagnetic wave so that it concentrates its energy in the immediate vicinity of the guiding structure and is, therefore, focused into a narrow beam for maximum range.

The conventional designs for radar and other highly directive antennas have a comparatively low aperture efficiency, normally of the order of 50 percent, and are extremely sensitive to dimensional tolerances and deflections. The configuration of conventional antennas, such as the parabolic reflector type, makes it difficult to control the side lobe energy level and requires the use of heavy, complex mechanical supporting structure. In aircraft installations large radomes, which are very difficult and expensive to design and manufacture, are required to house the antenna and even then there is an inefficient utilization of the radome volume. All of these factors when considered separately or in combination, clearly show a need for a completely new approach to the antenna design problem.

While one of the primary objects of this invention is to provide a traveling wave device for retarding the velocity of propagation of electromagnetic energy, it is also an important object to provide an antenna which is highly directive for effecting efficient utilization of associated electronic equipment.

Another object of this invention is to provide a highly directive retarded wave antenna particularly suited to airborne electronic applications wherein the antenna requires a very much smaller frontal area for a given performance than is obtainable with any of the known conventional designs. The smaller frontal area requirement for the antenna of this invention allows a material reduction in aerodynamic drag as compared with other antennas such as those of the parabolic reflector type.

Another object of this invention is to provide a highly directive retarded wave antenna of light-weight and rugged construction which virtually eliminates the difficulties normally associated with radome design, making the antenna particularly suitable for aircraft usage.

Another object of this invention is to provide a microwave antenna permitting greatly increased dimensional tolerances as compared with conventional antennas whereby the same is readily adapted to economical, mass production techniques in manufacturing.

Another object of this invention is to provide a highly directive retarded wave antenna having a high aperture efficiency and a narrow beam width for long range response.

Still another object of this invention is to provide a highly directive retarded wave antenna having a characteristic low side lobe energy level which may be substantially completely redirected into the main lobe pattern if desired through the use of an auxiliary phase correcting device.

Further and other objects will become apparent from

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a reading of the following description, especially when considered in combination with the accompanying drawings wherein like numerals refer to like parts.

In the drawing:

5 Figure 1 is a perspective view of a typical configuration of the retarded wave antenna of this invention;

Figure 2 is an enlarged fragmentary view of the perforated guide member having circular openings;

10 Figure 3 is a fragmentary view showing an arrangement of elongated openings for the perforated guide members;

Figure 4 is a plan view of the antenna illustrating the manner in which a highly directive beam is obtained;

15 Figure 5 is a fragmentary perspective view of the antenna incorporating a phase correcting cage for reducing the side lobe energy level;

20 Figures 6 and 7 are graphical presentations comparing the E and H plane beam patterns characteristic of the antenna of this invention with the beam patterns of a conventional antenna; and

Figure 8 is a perspective view of a waveguide incorporating the teachings of this invention.

Referring to Figure 1, the antenna includes a rectangular waveguide segment 1 having a pair of wide walls 2 and 3 and a pair of narrow walls 4 and 5 defining a passage generally rectangular in cross section and properly dimensioned to propagate electromagnetic energy in the desired mode. An antenna mounting bracket 6 is secured to one end of waveguide segment 1 for suitably coupling the antenna with associated electronic equipment, as indicated in Figure 4. A pair of waveguide extension members 7 and 8 are secured to the energy exit end 9 of waveguide segment 1 to form a two-walled horn type antenna structure effectively extending the wide walls 2 and 3 outwardly and forwardly of the tubular waveguide segment 1 to confine the energy in the electric or "E" plane direction, while leaving the antenna open in the magnetic or "H" plane direction. As most clearly shown in Figure 4, extension or guide members 7 and 8 flare outwardly from the wide walls of the waveguide and then are directed forwardly generally parallel to each other. While the spacing between parallel segments 12 and 13 of extension members 7 and 8 is not critical, indications are that optimum results may be obtained when they are spaced apart a distance approximately equal to twice the narrow dimension of the waveguide. Segments 12 and 13 on extension members 7 and 8 may be flared outwardly in alignment with segments 10 and 11 rather than extend in a parallel relationship without departing from the teachings of this invention, however control over the "H" plane beam pattern, as described hereinbelow, is then not as effective.

Antenna extension or guide members 7 and 8, as best shown in Figures 1 and 2, are provided with a large number of perforations or openings 14, which cause the average current paths on the guide members in both the "H" plane direction and in the direction of energy propagation to be longer than the corresponding actual dimension of the extension members. This retards the propagation of energy at the walls of the antenna and effectively narrows the beam width of the transmitted energy, particularly in the "H" plane, as hereinafter more fully explained. The arrangement of the perforations or openings 14 in extension members 7 and 8 to effect a phase delay function is most important to the teachings of this invention. The particular shape of holes 14 is not considered critical, however some hole shapes, as well as the size thereof, will obviously be more effective than others for a given antenna application, depending upon such factors as the power level and frequency of the energy being transmitted or received. For purposes of illustration, rather than limitation, the openings in extension members

7 and 8 are shown in Figure 2 as being generally circular in shape. These openings, having a diameter d , are arranged in a checkerboard fashion and spaced apart a distance equal to $2d$ as measured from center to center in a given row, such as 16, 17 and 18. In a direction normal to the longitudinal direction of the extension members, the openings in one row are spaced from the openings in adjacent rows a distance equal to d , the diameter of the openings. Also, the openings in one row are staggered relative to the openings in the adjacent rows, fixing the diagonal straight line distance between holes in adjacent rows at $\sqrt{2}d$ as indicated in Figure 2. With such an arrangement of openings in the extension members it is obvious that the shortest possible path length 19 in either the "H" plane direction or the direction of energy propagation for a section of the extension members as represented by the centerline spacing between adjacent openings in a given row is, by construction, equal to $2d$. The average path, illustrated by the construction line 19 in Figure 2, has a length equal to

$$\frac{\pi\sqrt{2}d}{2}$$

for the same distance along the extension member. This path is illustrated by the construction line 19 or 37 in Figure 2 and the equation for its length may be derived as follows:

Average path length = $\frac{1}{2}(2\pi R)$

$$= \frac{1}{2}\left(2\pi\frac{\sqrt{2}d}{2}\right) = \pi\frac{\sqrt{2}d}{2}$$

where R is the radius of the average path as measured from the center of the adjacent openings. By taking the ratio between the average path and the shortest possible path length, with the arrangement of openings shown in Figure 2, the average path length is approximately 1.11 times as long as the shortest possible path length. Thus, the above analysis indicates an approximate 11% increase in the path length for the electromagnetic energy transmitted or received by the antenna when employing such an arrangement of circular openings in the guide members. Test results indicate that the 11% figure is substantially equal to the effective relative dielectric constant for the perforated guide members, thus substantiating the theory of operation described above in effecting an electrical delay.

In order to efficiently obtain a guiding function from extension members 7 and 8 it is necessary to employ openings 14 having a size which is sufficiently small to prevent the same from resonating. Theoretically, this size in an opening circular in shape may be established as that which is something less than $\frac{1}{2}$ wave length of the energy at the guide members. Practically, this size limit may vary somewhat from the theoretical and, accordingly, the best antenna design for a particular use must, in the main, be determined by experimentation.

Test results indicate that the spacing between rows 16, 17 and 18 in the circular opening arrangement of Figure 2 in the direction of energy propagation should be no greater than the diameter d of the openings. The directivity of the antenna will be markedly reduced by increasing this row spacing while an increase in directivity will be realized by reducing the row spacing. Also, the delay effected in the direction of energy propagation should normally be at least as great as the delay in the "H" plane direction in order to obtain the full benefits of this invention.

It should be understood that while openings 14 in guide members 7 and 8 are shown and described as being circular in shape, other shapes may be employed for the openings without departing from the teachings of this invention. The primary requirement in this respect is that the openings be arranged to provide the desired delay action. Figure 3 shows an arrangement of elongated

openings 38 formed in conducting sheet material 39 similar to that used for guide members 7 and 8. The average current path length in sheet 39 in the direction represented by construction line 40 or "H" plane is substantially equal to the average current path length in the direction of energy propagation as represented by line 41 and the delay is somewhat greater than the delay effected by the perforations formed in the sheet, shown in Figure 2. By employing a sheet of conductive material having elongated openings like that shown in Figure 3, a delay action is effected in all directions in the plane of the sheet and the development of side lobes is even more effectively repressed. The use of elongated openings generally provides greater directivity than is obtainable with the use of circular openings and it is therefore preferable in most instances to use the elongated opening arrangement. It should be clearly understood, however, that other patterns and hole shapes may be employed and that the configurations shown herein are merely for purposes of illustration rather than limitation.

In transmitting energy through the antenna a highly directive beam is obtained by the action of the perforated guide members 7 and 8. While the reasons for the beam guiding action which takes place are not known as an absolute certainty, it is apparently due to delaying the propagation of energy flowing on or near the inner surfaces of the extension members, causing a large portion of the energy to concentrate at the outer edge of the transmitted beam, as indicated by lines 15 representing electric lines of force in Figure 4. That is, the energy in both the "H" plane and in the "E" plane, figuratively speaking, sticks to the walls of the guide members and as the energy is propagated in an axial direction relative to the antenna, a large part of the energy is concentrated in the outer portion of the beam. As a result, the energy leaving the antenna remains within a comparatively narrow beam pattern. The actual beam patterns obtained using an antenna like that shown in Figure 1 in conjunction with a phase corrector, as shown in Figure 5, is shown by Figures 6 and 7 which are plots of field strength on a decibel scale with respect to the angle from the centerline of the antenna as measured from the mouth or exit end 9. Figure 6 represents the beam pattern 21 in the electric field or "E" plane which is parallel to the narrow walls 4 and 5 of waveguide segment 1 and Figure 7 shows the beam pattern 22 in the magnetic field or "H" plane which is parallel to the wide walls 2 and 3 of waveguide segment 1. As seen from these two figures, the side lobe energy level is negligible, indicating the high efficiency of operation obtainable with the perforated guide members 7 and 8. Dotted lines 42 and 43 in Figures 6 and 7 respectively, show, superimposed on the beam patterns for the antenna of this invention, typical beam patterns characteristic of conventional antennas.

Figure 5 shows a cage 23 associated with extension members 7 and 8 of the basic antenna described above in connection with Figures 1, 2 and 4. The function of cage 23 is to provide phase correction for the energy in the "H" plane parallel to the wide walls of the waveguide segment 1. Cage 23 may be of any suitable conductive material and need not be perforated as are the extension members 7 and 8 of the basic antenna. Walls 24 and 25 of the cage, which are located in parallel planes normal to the plane of guide members 7 and 8, should be spaced apart a distance approximately equal to twice the wide dimension of waveguide 1 for maximum effectivity. The action of the cage is to re-direct the side lobe energy into the main beam.

Side walls 26 and 27 on cage 23 are primarily structural members for supporting walls 24 and 25 and it should be understood that any suitable means for supporting walls 24 and 25 may be employed without materially altering the electrical properties of the antenna or departing from the teachings of the invention.

The location of phase correcting cage 23 in an axial

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direction parallel with the direction of energy propagation will depend upon a number of factors such as the wave length and power level of the energy being transmitted or received. By shifting phase correcting cage 23 along guide members 7 and 8 a tuning effect is obtained which, for a given wave length, will provide the optimum antenna operating efficiency. Where broad band operation is the primary consideration and control over the side lobe level of the beam pattern is of secondary importance, it may be desirable to eliminate the use of a phase correcting cage.

The antenna may be used in the same manner as any conventional horn type waveguide antenna for transmitting and/or receiving electromagnetic energy since a good transmitting antenna is also a good receiving antenna. A typical system using the antenna is illustrated in Figure 4 wherein a duplexer 29 connects with waveguide segment 1 of the antenna and with a transmitter 30 through waveguide 31 as well as with a receiver 32 through waveguide segment 33. Duplexer 29 effectively isolates the receiver from the transmitted energy and the transmitter from received energy in the conventional manner, thus allowing the antenna to serve both transmitting and receiving functions.

The broad concept of perforating the walls of the guiding members for delaying the propagation of electromagnetic energy is applied in Figure 7 to a rectangular waveguide section to illustrate another application of the principle employed herein for increasing the directivity of an antenna. Perforations 36 in waveguide 35 are arranged relative to each other in the manner previously described in connection with the antenna for effecting a phase delay in the propagation of energy therethrough, thus enabling the waveguide segment to serve as a fixed waveguide phase shifter which is light in weight and economical to manufacture.

While the use of perforated conducting sheet material is considered best for carrying out the teachings of this invention it should be understood that equivalents such as solid material with non-conducting and non-interconnecting coated areas or inserts of dielectric material which will electrically produce the delay action of the perforated sheet by providing an undulative path for current flow in the plane of the sheet may also be employed.

As is particularly apparent from Figures 2 and 3, the hole patterns for effecting a delay in the velocity of propagation of energy will produce serrated edges on extension members 7 and 8 if the pattern is made uniform over the entire planform area. These serrated edges have the effect of increasing the side lobe energy level to a small degree and hence it is normally desirable to fill in the recesses at the edges of the extension members with a conducting material or better yet provide a thin strip of conducting material at the edges, such as shown at 44 in Figure 2.

The concept of effecting a delay in the propagation of electromagnetic energy through the use of perforated conducting sheet material is useful not only as applied to the antenna described herein but in many other electronic applications relating to traveling wave devices in general and it is, therefore, to be understood that certain alterations, modifications and substitutions such as those pointed out hereinabove may be made to the instant disclosure without departing from the spirit and scope of the invention as defined by the appended claims.

I claim:

1. A highly directive retarded wave antenna comprising a generally rectangular waveguide, said waveguide having a pair of wide walls and a pair of narrow walls properly dimensioned for propagating electromagnetic energy therethrough in the desired mode, and a conducting waveguide extension member secured to each wide wall and having a width at least as great as the wide wall, the conducting extension members being flared outwardly and

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forwardly of the waveguide and having a plurality of openings formed therein and arranged relative to each other so that the average current paths in the direction of energy propagation and in the "H" plane direction are longer than the corresponding straight line dimension on each extension member whereby an electromagnetic wave traveling through the antenna is delayed and thereby formed into a narrow beam.

2. A highly directive retarded wave antenna comprising a waveguide through which electromagnetic energy may be propagated, spaced conductive guide members projecting outwardly and forwardly from one end of said waveguide and forming a flared horn for guiding energy from the waveguide into free space, said guide members having a plurality of openings formed therein arranged relative to each other so that the average current paths on the extension members are made effectively longer than the actual dimensions of the guide members whereby an electromagnetic wave is focused into a narrow beam, and phase correcting cage means carried by said extension members for controlling the side lobe energy level.

3. A highly directive retarded wave antenna comprising a waveguide through which electromagnetic energy may be propagated, and spaced conductive guide members projecting outwardly and forwardly from one end of said waveguide and forming a flared horn for guiding energy from the waveguide into free space, said guide members having a plurality of openings formed therein arranged relative to each other so that current paths on the guide members are longer than the actual corresponding dimension of the extension members whereby an electromagnetic wave may be focused into a narrow beam.

4. A highly directive retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, and a pair of generally flat, spaced conductive guide members projecting outwardly and forwardly from one end of said waveguide and forming a two walled flared horn for guiding energy from the waveguide into free space, said guide members being perforated substantially throughout the length thereof, said perforations being spaced apart in staggered rows defining an undulative path for current flow axially of the waveguide whereby the average current path length in the direction of energy propagation is longer than the corresponding straight line dimension of the guide members for focusing the electromagnetic energy into a narrow beam.

5. A highly directive retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, a pair of generally flat, spaced conductive guide members projecting outwardly and forwardly from one end of said waveguide and forming a two walled flared horn for guiding energy from the waveguide into free space, said guide members being perforated substantially throughout the length thereof, said perforations being spaced apart in staggered rows defining an undulative path for current flow on the surface of the guide members whereby the average current path length in the direction of energy propagation is longer than the corresponding dimension of the guide members whereby electromagnetic energy may be focused into a narrow beam, and phase correcting plates carried by the antenna and closing the open sides of the antenna between the spaced conductive guide members throughout at least a portion of the length thereof whereby to control the side lobe energy level.

6. A highly directive retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, and spaced conductive guide members projecting outwardly and forwardly from one end of said waveguide and forming a flared horn for guiding energy from the waveguide into free space, said guide members being perforated substantially throughout the length thereof, said perforations being spaced apart in staggered relationship defining an undulative path for current flow

whereby the current path length is effectively lengthened for focusing electromagnetic energy into a narrow beam.

7. A retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, and perforated conductive guide members secured to said waveguide and projecting outwardly and forwardly from one end thereof and forming a flared horn for guiding energy between the waveguide and free space, the perforations in said guide members being no greater in the maximum dimension than $\frac{1}{2}$ wavelength of the energy in the waveguide and arranged in staggered relationship requiring an undulative path for current flow axially of the waveguide whereby to retard the propagation of energy at the surface of the conductive guide members for focusing the energy into a narrow beam.

8. A retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, perforated conductive guide members secured to said waveguide and projecting outwardly and forwardly from one end thereof and forming a flared horn, the perforations in said guide members being no greater in the maximum dimension than $\frac{1}{2}$ wavelength of the energy in the waveguide and arranged in staggered relationship requiring an undulative path for current flow axially of the waveguide whereby to retard the propagation of energy at the surface of the conductive guide members for focusing the energy into a narrow beam, and opposed phase correcting plates carried by the antenna forwardly of said waveguide and co-axially with said guide members for controlling the side lobe energy level.

9. A retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, and conductive guide members secured to said waveguide and projecting outwardly and forwardly from one end thereof and forming a flared horn, said conductive guide members having isolated non-conductive areas arranged in a substantially uniform pattern throughout the length thereof effecting an undulative path for current flow therealong in the planes of the guide members for retarding the propagation of energy and increasing the antenna directivity.

10. A retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, said waveguide being generally rectangular in cross section defining a pair of narrow and a pair of wide walls, and a pair of spaced conductive guide members secured to the wide walls of the waveguide and projecting outwardly and forwardly from one end thereof to form a flared horn, said guide members having isolated dielectric areas arranged in a substantially uniform pattern effecting an undulative path for current flow therealong in the respective planes of the guide members whereby to retard the propagation of energy and to increase the antenna directivity.

11. A highly directive retarded wave antenna comprising, a waveguide through which electromagnetic energy may be propagated, spaced conductive guide members projecting outwardly and forwardly from one end of said waveguide and forming a flared horn for guiding energy from the waveguide into free space, said guide members being perforated substantially throughout the length thereof to provide a plurality of non-conducting dielectric areas on the surface thereof, said perforations being spaced apart in staggered relationship defining an undulative path for current flow whereby the current path is effectively lengthened for focusing electromagnetic energy into a narrow beam, and conducting material secured to the edges of said guide members and closing the perforations appearing at the edge thereof whereby to minimize the side lobe energy level.

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