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WAVE-GUIDE ANTENNA

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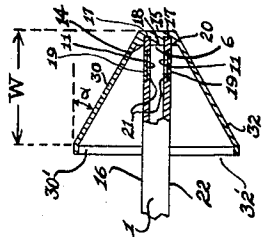


Fig. 2

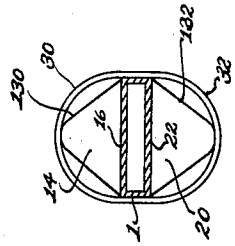


Fig. 3

Fig. 1

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WAVE-GUIDE ANTENNA

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6 Claims. (Cl. 343—781)

The present invention relates to wave-guide antennas and, more particularly, to antennas of the type embodying a surface reflector cooperating with a slotted wave-guide structure.

Various techniques have been proposed and utilized for feeding radio-frequency energy to surface reflecting elements, such as paraboloidal reflectors. A wave-guide transmission line, for example, has been mounted through the vertex region of a paraboloidal reflector along the axis of the reflector, with the mouth of the guide terminating near the reflector focus. A secondary reflector surface positioned beyond the mouth of the guide redirects the waves propagated along the guide back upon the paraboloidal reflector, whence the waves are directed as a beam into space. This same structure has, of course, been used, also, as a device for receiving radio waves from space. In order to effect this radio-wave feeding-and-directing process efficiently, it has been proposed to terminate the wave-guide mouth, which may be of rectangular cross section, in a resonant chamber of transverse dimensions larger than the smaller wave-guide transverse dimension. Slots are provided in the surface of the resonant chamber facing the paraboloidal reflector parallel to each of the wider sides of the guide, thereby permitting energy to flow from the slots to the portions of the reflector disposed on each side of the guide, or to permit energy to pass from each portion of the reflector into the corresponding slot of the resonant chamber. Among the disadvantages of such systems, is the mechanical complexity of the structure and the difficulty in fabricating the same. It is usually customary to taper the wave guide as it joins the resonant chamber in order that the slots in the chamber may be placed close enough together with respect to the wave-length of the radio energy to appear substantially as a point source. It is quite difficult and costly, however, to provide these tapers in wave-guide structures, and it is expensive and complicated to manufacture and assemble the associated resonant chambers. A further disadvantage of such systems resides in the relatively narrow band of radio frequencies that can be used with tapered guides and resonant chambers.

In United States Letters Patent No. 2,778,016, issued January 15, 1957 to Lan J. Chu, there is disclosed a new and improved antenna embodying a wave-guide transmission line of this character that is not subject to the above-mentioned disadvantages and that, on the contrary, is easy and less costly to manufacture, and is adapted for wide-band frequency operation. To achieve these ends, the antenna comprises a longitudinally extending wave guide within the interior of which radio waves of predetermined electric-vector polarization may be longitudinally propagated and provided near its mouth with a pair of slots communicating with the interior of the guide through oppositely disposed transverse side-wall portions of the guide substantially perpendicular to the plane of the said electric vector. A substantially planar conducting surface closes off the mouth of the guide and extends

outward beyond the said side-wall portions of the guide in a plane substantially parallel to the plane of the said electric vector and perpendicular to the longitudinal axis of the wave guide. This antenna has been found to operate very successfully in practice.

There are occasions, however, where strict limitations are placed upon the allowable magnitude of radiation side lobes. In addition, increased efficiency is sometimes demanded, namely, greater gain for the same radiation beam width. In my copending application, Serial No. 617,048 filed October 19, 1956 for Wave Guide Antenna, this end is achieved through providing appropriate conductive chambers overlapping the before-mentioned radiating slots. Where such antennas are to be employed for operation over relatively wide frequency bands, however, the conductive chambers may introduce difficulties in providing selective frequency operation because of their fixed dimensions and in providing unsatisfactory impedance-matching over the complete frequency bands. An object of the present invention, accordingly, is to provide a new and improved slotted wave-guide structure of the above-described type that, while providing greatly reduced side-lobe radiation and increased efficiency, also provides improved wide-band frequency operation and impedance-matching. In summary, this result is accomplished through converging the walls of the slot-overlapping conductive chambers towards the closed end of the guide.

Other and further objects will be explained hereinafter and will be more particularly pointed out in the appended claims.

The invention will now be described in connection with the accompanying drawing, Fig. 1 of which is a fragmentary perspective view of the invention in preferred form, partly broken away to illustrative details of construction; and

Figs. 2 and 3 are sections upon a somewhat reduced scale taken upon the lines 2—2 and 3—3 of Fig. 1, respectively, looking in the direction of the arrows.

A longitudinally extending wave-guide transmission-line section 1 of rectangular configuration is shown passing through a rectangular hole 2 in the vertex region of a paraboloidal reflector 3 and extending along the axis of the reflector. The guide 1 is mounted in the vertex region 2 by bolting a bracket 4 secured thereto to the outer surface of the reflector 3, shown to the left in Fig. 1. An annular conducting plate 5 is mounted upon the inner surface of the reflector in the vicinity of the vertex region 2. The guide 1 may be fed with radio energy from, or may feed radio energy to, a further guide section 9, coupled to the guide 1 at the left of the reflector 3, by a conventional wave-guide flange coupling 7. The further guide section 9 may be connected to a receiver or transmitter, not shown.

The mouth or right-hand end 6 of the guide 1 is received in a rectangular recess 17, more particularly shown in Fig. 2, formed intermediately of a planar conducting surface or plate 15 disposed preferably at right angles to the guide 1. The base or end 18 of the recess 17 thus closes off the mouth 6 of the guide 1. Transverse planar recesses 21, Fig. 2, preferably of rectangular shape, are formed, as by milling, in oppositely disposed side walls of the wave guide 1, illustrated as the upper and lower walls 16 and 22, near the mouth or end 6 of the guide. Transverse slots 11 are cut, as explained in the said Letters Patent and copending application, through the upper and lower walls intermediate the milled recesses 21 to cooperate with the inner space of the guide 1, which may be air or any other desired dielectric medium. In order to protect the slots 11 from the atmosphere and to adapt the medium within the wave guide for pressuring, if desired, windows 19 having substantially the same dimensions as the recesses 21 are secured within the re-

cesses 21, thereby hermetically sealing the slots 11. The thickness of the windows 19 preferably corresponds to the depth of the recesses 21 in order that the outer faces of the windows 19 may be substantially flush with the adjacent outer surfaces of the wave-guide 1. The windows 19 may be of any desired radio-wave transparent material, such as polystyrene and the like, though a preferred window is constituted of Corning Type 707 glass.

As explained in the said Letters Patent and copending application, the depth of the conducting-surface recess 17 preferably corresponds to, just slightly less than, the distance from the mouth 6 of the guide 1 to the edge of each slot 11 further from the reflector 3, in order that the said edge may lie substantially in the plane of the surface of the conducting plate 15, facing the reflector 3. As will later be explained, however, certain variations in the position of the slot may be tolerated. The ends of the milled sections 21 of the guide 1 at the mouth 6 may be secured in place in the recess 17 by soft solder, the recess 17 being of somewhat larger dimensions than the transverse guide dimensions in order to permit the securing process to be effected with ease and to facilitate removal of the same, if necessary.

Ignoring, for the moment, the conducting-chamber surfaces 30 and 32, radio waves propagated longitudinally along the guide 1 toward its mouth 6, in, for example, the $TE_{0,1}$ mode, having vertical electric-vector polarization, represented by E, are radiated through the upper and lower slots 11, the slots lying in planes perpendicular to the electric vector. In the absence of the chambers 30 and 32, the energy radiated through the slots 11 would become initially guided between the upper and lower outer surfaces 16 and 22 of the guide 1 and the adjacent respective upper and lower portions 14 and 20, Figs. 2 and 3, of the plate 15. From another point of view, the slots 11 may be considered as exciting elements disposed substantially along the vertex of a pair of substantially right-angularly disposed corner guiding surfaces 14—16 and 20—22. The energy would thus be directed back along the upper and lower outer surfaces of the guide 1, reflecting from the upper and lower surface portions 10 and 12 of the reflector 3, thereby being directed as a beam into space, as explained in the said Letters Patent and copending application. Since the separation between the upper and lower guide side-walls 16 and 22 of a rectangular guide operated as above described can be made small compared to the wavelength of the radio energy, the slots 11 are rather close together and for all practical purposes behave substantially as a single point source, thus taking advantage of the parallel-ray focusing properties of the paraboloidal reflector 3 to produce the beforementioned directive beam in space. The reverse process takes place in reception of energy from space.

The optimum position of the slots 11 for producing the most satisfactory undistorted major radiation lobe in the plane of the electric vector, consistent with maximum antenna gain, has been found to be that previously described with the slot 11 lying just outside the plane of the inner surface of the conducting plate 15. It has been determined, however, that satisfactory, though less desirable, results can be obtained if the slots 11 are disposed somewhat closer to the paraboloidal reflector 3, though intolerable distortion of the radiation lobe pattern and loss of antenna gain has been found to occur if the slots 11 are spaced closer to the reflector 3 than about one-quarter of the wavelength of the radio energy from the position shown in Figs. 1 and 2. It has also been determined that the transverse dimension of the upper and lower portions 14 and 20 of the plate 15 should have a value not greater than one-half of the said wavelength for the wide-band operation and impedance-matching purposes of the present invention. The length of the slots 11 is rather critical, though variations in the width of the slots may be effected. Undesirable effects produced by that energy which is reflected from the reflector 3 back into the slots 11 may be minimized with the aid of the previously described plate 5 superimposed upon the reflector 3 about the guide 1. While some energy reflected from the outer portions of the reflector 3 may re-enter the slots 11, cancellation or substantial cancellation thereof at the slots 11 has been found to occur as a result of reflections from the surface of plate 5 protruding closer to the slots 11 than the adjacent portions of the reflector 3. This effect, moreover, takes place over a relatively broad band of frequencies.

In accordance with the present invention, however, the slots 11 are not left free to radiate upward and downward into space as in the antenna of the said Letters Patent. To the contrary, upper and lower hollow conductive-chamber surfaces 30 and 32 are provided extending from the upper and lower end-plate surfaces 14 and 20 back toward the reflector 3. As is explained in the said copending application, it has been found that if, first, the length W, Fig. 2, of these chambers 30 and 32 is sufficient to overlap the slots 11 and to extend at least substantially a half-wavelength from the end plate 15, and even up to substantially three-quarters of the wavelength; and, if, secondly, the maximum chamber height is about a half-wavelength, but not greater than substantially three-quarters of a wavelength, an extremely beneficial result takes place. That result is the vastly improved reduction in side lobes of the radiation pattern and increased radiating efficiency. The explanation of this experimentally verified result may reside in the fact that the chambers 30 and 32 will be excited by radiation through the slots 11, acting as wave-guide radiators having substantially the same mode of electromagnetic field as the original guide 1. The radiation that normally "spills over" or is wasted when the slot radiation upward and downward is unconfined, as in the antenna of the said Letters Patent, contributes to the production of side lobes and the diminution of energy in the primary radiation lobe or pattern. Since this slot-radiated energy is now confined to travel through the chambers 30 and 32 directly rearward toward the reflector 3, more energy is maintained in the primary lobe, resulting in greater efficiency and markedly reduced side-lobe radiation.

While, in some cases, as further explained in the said copending application, the chambers 30 and 32 might constitute merely walls of a cylinder extending rearward from the complete peripheral border of the plate 15, it is often desirable to maintain the horizontal radiation pattern relatively broad. This may be achieved by limiting the maximum transverse dimension of the chambers 30 and 32 to the width of the guide 1, as by terminating the surfaces 30 and 32 at the side walls of the guide 1, as shown more particularly in Fig. 3. Other surface configurations 30 and 32, including rectangular chambers, may also be employed, though the illustrated oval configuration has been found to operate very satisfactorily.

Not only does the above-described construction eliminate the necessity for tapering the wave guide and for providing resonant slotted chambers, but this construction is admirably suited to rapid and accurate mass-production techniques. It has been observed that this structure, in addition, illuminates or feeds the reflector aperture in such a manner as to provide greatly reduced secondary lobes in the radiation pattern and increased efficiency.

In accordance with the present invention, however, the chambers 30 and 32 are so designed as to prevent frequency-selective operation that is normally inherent in fixed-chamber systems and poor impedance matching at particular frequencies in a relatively wide band of frequencies with which the antenna is to be employed. It has been found that by causing the chambers to converge substantially conically toward the end plate 15 closing off the wave-guide mouth 6, this very desirable end of wide-band frequency operation can be achieved. With regard to wide-band impedance matching, it should be

observed that two problems are presented: first, wide-band matching between the slots **11** and the chambers **30** and **32**; and secondly, wide-band matching between the chambers **30** and **32** and the space between the chamber mouths **30'** and **32'** and the reflector **3**. Fortunately, the converging construction before mentioned has been discovered simultaneously to accomplish both of these wide-band impedance-matching effects, particularly when the uppermost and lowermost portions of the chambers **30** and **32** are provided with substantially planar intermediate regions **130** and **132**, corresponding to the intersection with the substantially conical chambers **30** and **32** of planes extending from substantially the uppermost and lowermost portions of the apertures **30'** and **32'** toward the end plate **15**.

The optimum angle α of convergence of the substantially conical chambers **30** and **32** with their preferably substantially planar upper and lower regions **130** and **132**, Fig. 2, has been found to be substantially thirty-two and a half degrees, with highly satisfactory results for various purposes obtainable with angles α differing by as much as substantially ± 25 percent from that optimum angle.

In order to simulate a point source, as before mentioned, the slots **11** may be brought closer together by reducing the height of the terminal section of the guide **1** containing the slots **11**. The point of transition **1'** between the left-hand greater-dimensional guide section **1** and the said terminal section should be located sufficiently rearward of the apertures or mouths of the chambers **30** and **32** to prevent restriction of the energy directed therefrom. A guide **1** of uniform dimensions throughout, however, may be employed, if desired. The apertures or mouths of the chambers **30** and **32** may be covered with weatherproof, radio-wave permeable windows **30'**, **32'**, as of $\frac{1}{16}$ of an inch thick polystyrene and the like.

As an illustration of typical dimensions, given in units of inches instead of fractions of a wavelength, though they may easily be converted into such, an antenna for operation over the band of from 6875 to 7125 megacycles may utilize a $TE_{0,1}$-mode-operated wave guide **1** having side walls about $\frac{1}{16}$ of an inch thick. The recesses **21** may be about $\frac{1}{32}$ of an inch deep and about $\frac{1}{4}$ of an inch wide. The slots **11** may be about $\frac{9}{10}$ of an inch long and $\frac{3}{16}$ of an inch wide and spaced about $\frac{3}{32}$ of an inch from the mouth **6** of the guide **1**. The depth of the recess **17** in the conducting plate **15** may also be about $\frac{3}{32}$ of an inch for optimum results. The chambers **30** and **32** may be of overall length W about one inch; the plate **15** may have a height of $\frac{15}{16}$ of an inch; the chamber apertures or mouths **30'** and **32'** may have a height of about $\frac{3}{4}$ of an inch; the substantially conical chambers **30** and **32** may have a transverse radius of about three-quarters of an inch, and an angle of convergence α of about 32½ degrees.

Extremely low-energy secondary lobes have been produced with this structure in the vertical and horizontal radiation pattern, respectively, with substantially constant voltage standing-wave ratios, indicating impedance matching of substantially 1.06 at the low end of the band, 1.10 at the mid-band frequency, and 1.05 at the high end of the band.

While, as before explained, the rectangular guide **1** is particularly well-suited to the purposes of the present invention inasmuch as the height dimension, shown vertical, may be small compared to the wave length of the radio energy, so that the slots **11** may be close together, if some distortion can be tolerated, the same technique may be applied to wave guides of other configuration, such as guides that are oval, including substantially circular, in cross section.

While, moreover, the invention has heretofore been described in connection with the use of such systems as transmitting apparatus, it is to be understood that they are equally well suited for the reception of radio waves. The slotted wave guide and end-plate structure, moreover, may find application as an antenna in and of itself, without the use of a surface reflector **3**, to obtain radiation patterns of the character produced by such a slotted guide. If desired, furthermore, but a single slot may be utilized where symmetrical results are not wanted. A plurality of unsymmetrically disposed slots may also be employed, if unsymmetrical patterns are to be achieved, the plurality of slots, for example, being parallel to one another on one side only of the guide. While the slots **11** have been shown as provided with rounded ends, this is merely because a milling machine may produce such ends. It is to be understood, however, that the slots may be of strictly rectangular or other configuration and that they may be formed by punching and other processes as well. Similarly the plates **15** may be of other configuration than rectangular. The length and orientation of the slots may also be varied depending upon the desired radiation pattern configuration. As a further illustration, the terminal slots may be provided in the narrower side walls parallel to the wave-guide axis and perpendicular to the end plate **15**.

Further modifications will occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A longitudinally extending wave guide of substantially rectangular cross section closed at one end having a slot in a wall of the guide near the said end, and a conducting surface spaced from and extending longitudinally back along the said wall overlapping the said slot and converging toward the said end of the guide, the said conducting surface terminating along its side edges at the side edges of the said wall of the guide.

2. A longitudinally extending wave guide closed at one end having a slot in a predetermined portion of wall surface of the guide near the said end, and a conducting surface spaced from and extending longitudinally back along the said predetermined portion of wall surface and shaped to provide a chamber between the said predetermined portion of wall surface and the conducting surface converging toward the said end of the guide and overlapping the said slot in order to be excited by radiation passing through the slot, the chamber terminating at the sides of the said predetermined portion of wall surface in order to provide a chamber aperture the width of which corresponds to the width of the guide between the sides of the said wall.

3. A longitudinally extending wave guide closed at one end having a slot in a predetermined portion of wall surface of the guide near the said end, a first conducting surface disposed at an angle to the wave guide at the said end and extending transversely beyond the said predetermined portion of wall surface, and a second conducting surface extending longitudinally from the first conducting surface back along the said predetermined portion of wall surface and shaped to provide a chamber having the said predetermined portion of wall surface and the first conducting surface as its other bounding surfaces and overlapping the said slot in order to be excited by radiation passing through the slot, the chamber terminating at the sides of the said predetermined portion of wall surface in order to provide a chamber aperture the width of which corresponds to the width of the guide between the sides of the said predetermined portion of wall surface, and the second conducting surface converging with the said predetermined portion of wall surface of the guide toward the said end thereof.

4. A longitudinally extending wave guide closed at one end having a slot in a predetermined portion of wall surface of the guide near the said end, a first conducting surface disposed at an angle to the wave guide at the said end and extending transversely beyond the said predetermined portion of wall surface, and a second conducting surface extending longitudinally from the first

conducting surface back along the said predetermined portion of wall surface and shaped to provide a chamber having the said predetermined portion of wall surface and the first conducting surface as its other bounding surfaces and overlapping the said slot in order to be excited by radiation passing through the slot, the chamber being of oval cross-section substantially conical in surface converging toward the said end of the guide and terminating at the sides of the said predetermined portion of wall surface in order to provide a chamber aperture the maximum width of which corresponds to the width of the guide between the sides of the said predetermined portion of wall surface.

5. A longitudinally extending wave guide closed at one end having a pair of slots in oppositely disposed side wall surface portions of the guide near the said end, a first conducting surface disposed at substantially right angles to the said side wall surface portions of the wave guide at the said end and extending transversely beyond the said side wall surface portions, and further conducting surfaces extending longitudinally from the first conducting surface back along the said side wall surface portions and shaped to provide substantially conical chambers overlapping the said slots in order to be excited by radiation passing through the slots and converging toward the said end of the guide, the chambers terminating at the sides of the said side wall surface portions of the guide in order to provide chamber apertures the width of which correspond to the width of the guide between the said sides of the said wall surface portions.

6. A wave guide as claimed in claim 5 and in which the cross-sectional configuration of the guide is substantially rectangular and the said side wall surface portions are substantially parallel to one another.

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