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SEARCH ROOM

Jan. 10, 1956 M. KATCHKY ET AL 2,730,717

DIRECTIONAL WAVE ANTENNA FOR MARINE RADAR USE

Filed Jan. 16, 1952 5 Sheets-Sheet 1

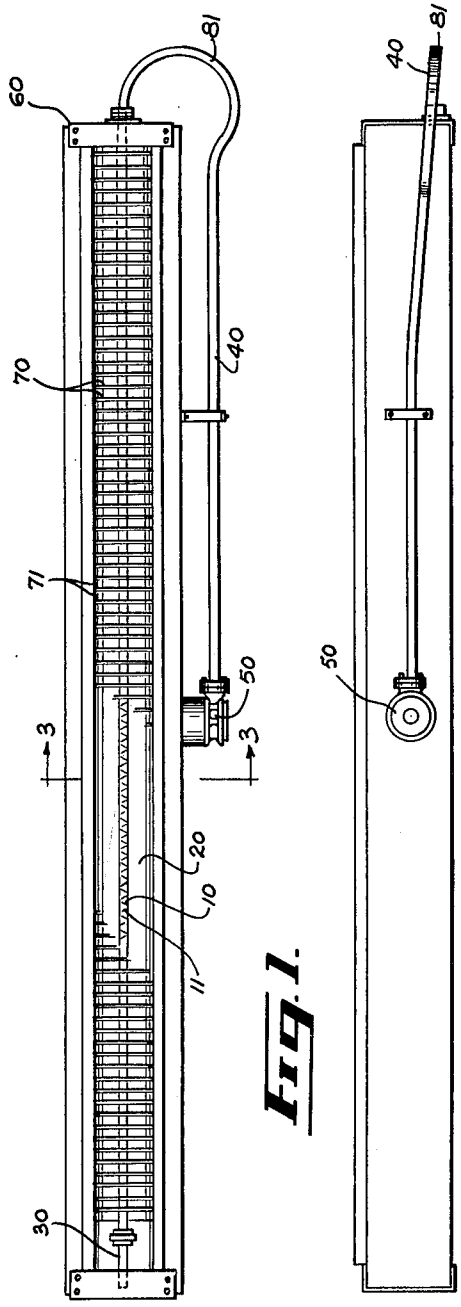


Fig. 1.

Fig. 2.

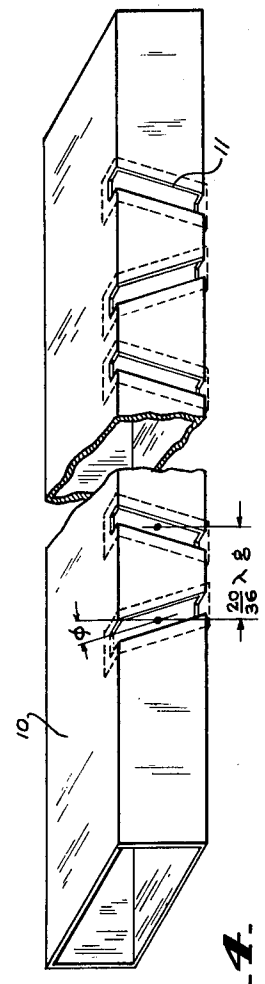


Fig. 4.

INVENTORS
MAX KATCHKY
HUGH GORDON BYERS

BY Briley, Stephens & Huettig
ATTORNEYS

Jan. 10, 1956 M. KATCHKY ET AL 2,730,717

DIRECTIONAL WAVE ANTENNA FOR MARINE RADAR USE

Filed Jan. 16, 1952 5 Sheets-Sheet 2

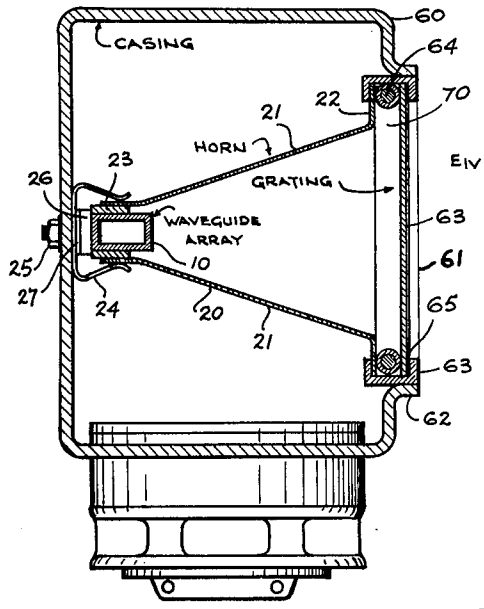


Fig. 3.

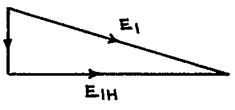


Fig. 11a.

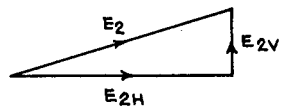


Fig. 11b.

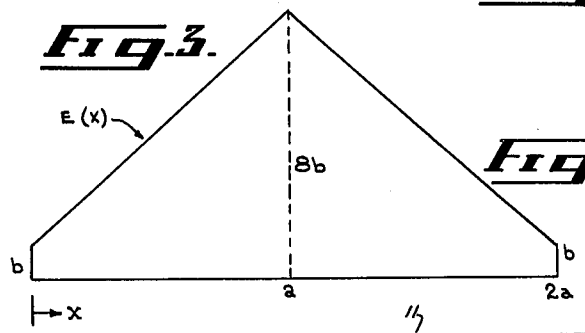
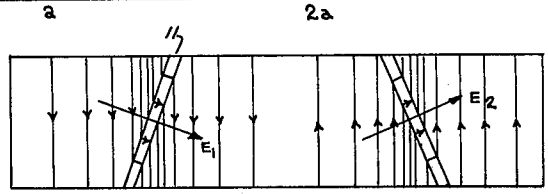


Fig. 6.



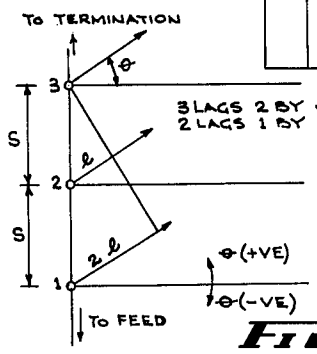




Fig. 10.

Fig. 12.

INVENTORS
MAX KATCHKY
HUGH GORDON BYERS
BY Bailey, Stephens & Hiller
ATTORNEYS

DIRECTIONAL WAVE ANTENNA FOR MARINE RADAR USE

Filed Jan. 16, 1952 5 Sheets-Sheet 3

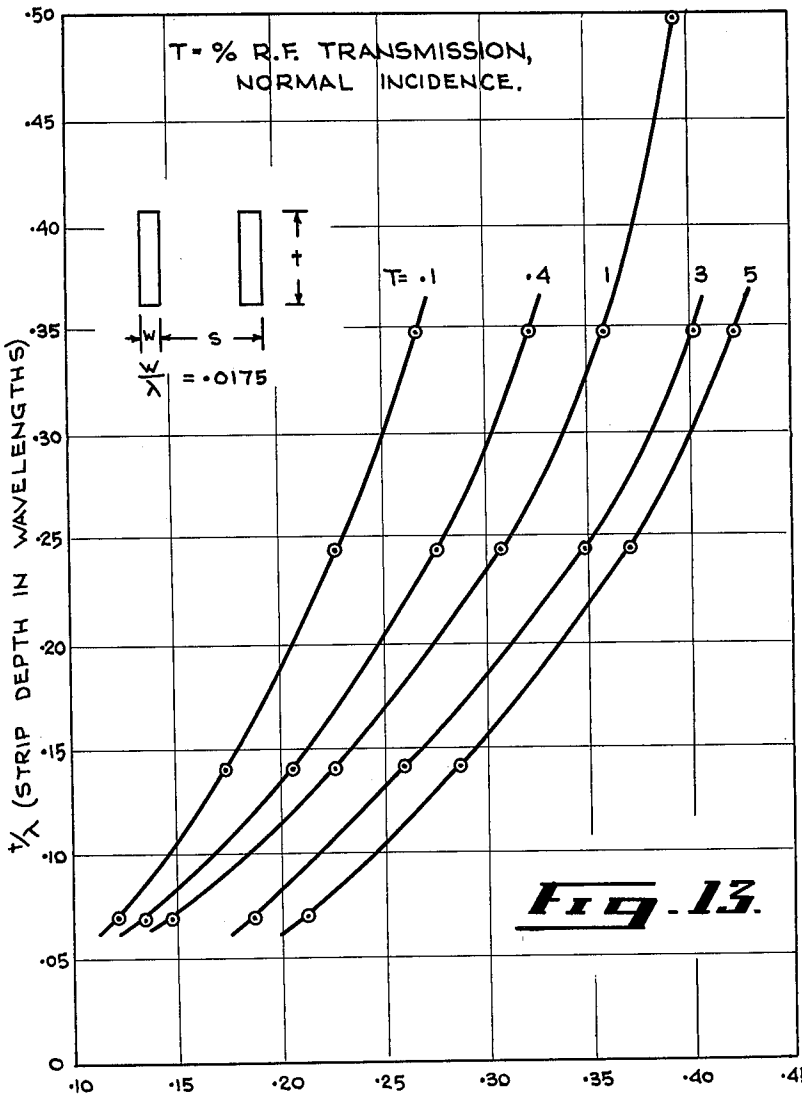


Fig. 13.

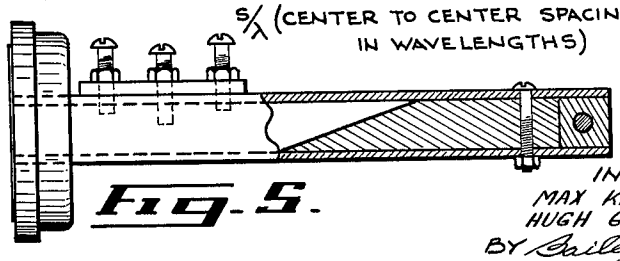


Fig. 5.

INVENTORS
MAX KATCHKY
HUGH GORDON BYERS
BY Bailey, Stephens & Hiettig
ATTORNEYS

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DIRECTIONAL WAVE ANTENNA FOR MARINE RADAR USE

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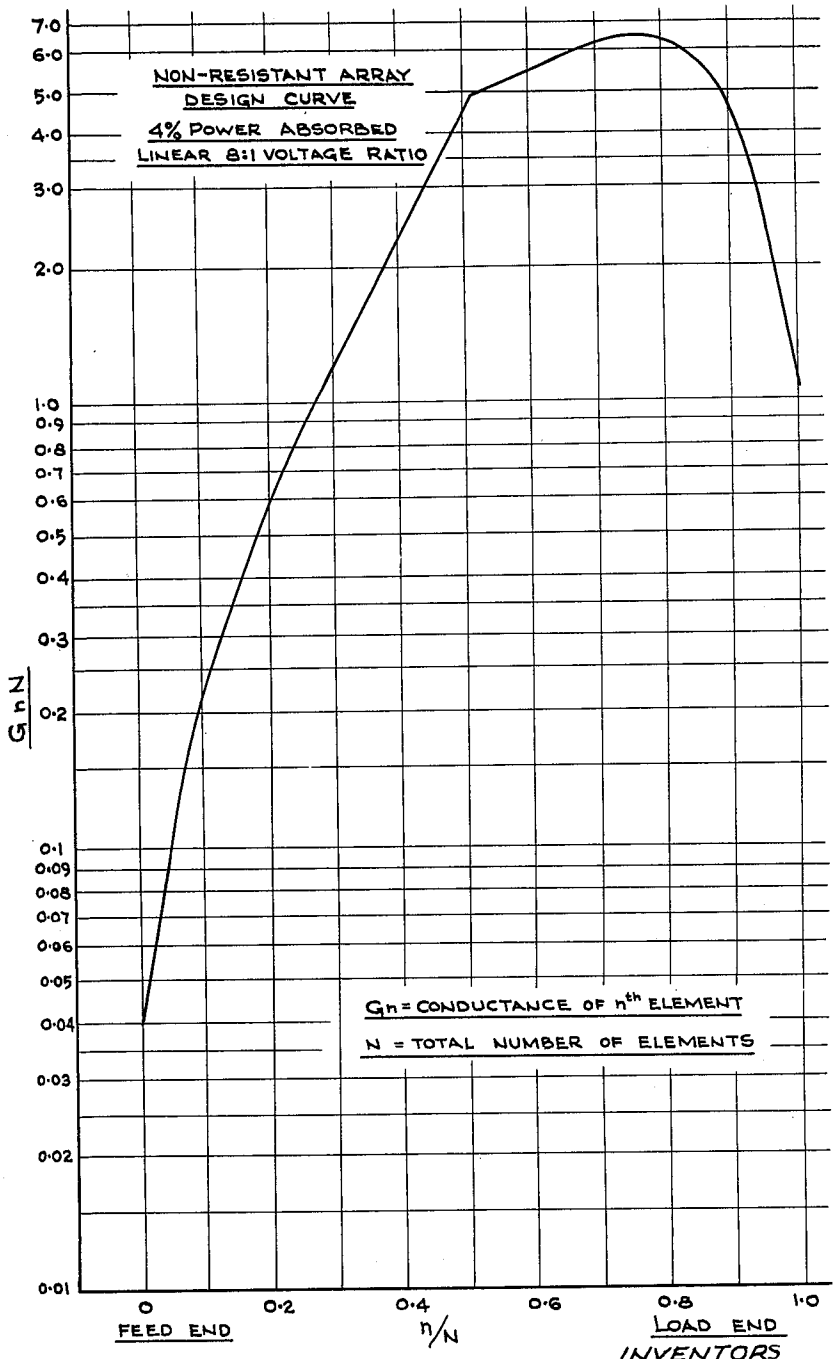


Fig. 8.

INVENTORS
MAX KATCHKY
HUGH GORDON BYERS
BY Bailey, Stephens & Huettig
ATTORNEYS

Jan. 10, 1956 M. KATCHKY ET AL 2,730,717

DIRECTIONAL WAVE ANTENNA FOR MARINE RADAR USE

Filed Jan. 16, 1952 5 Sheets-Sheet 5

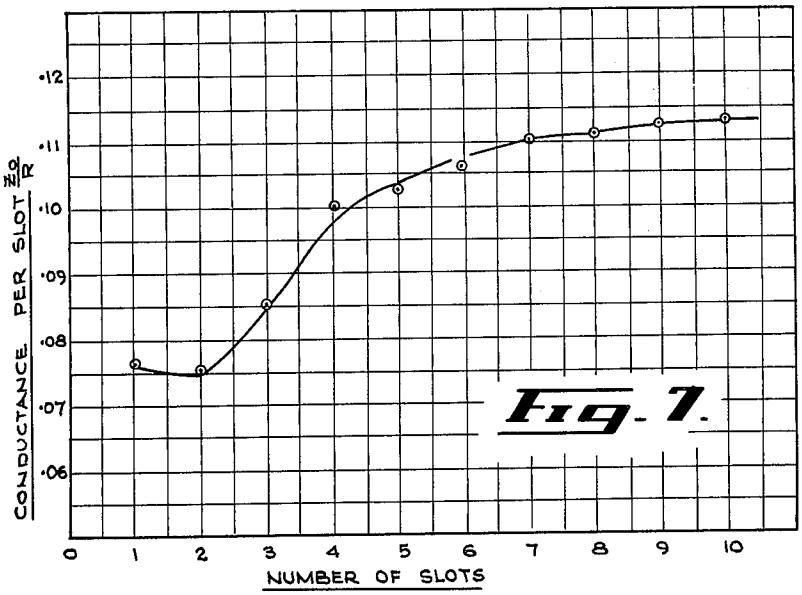


Fig. 7.

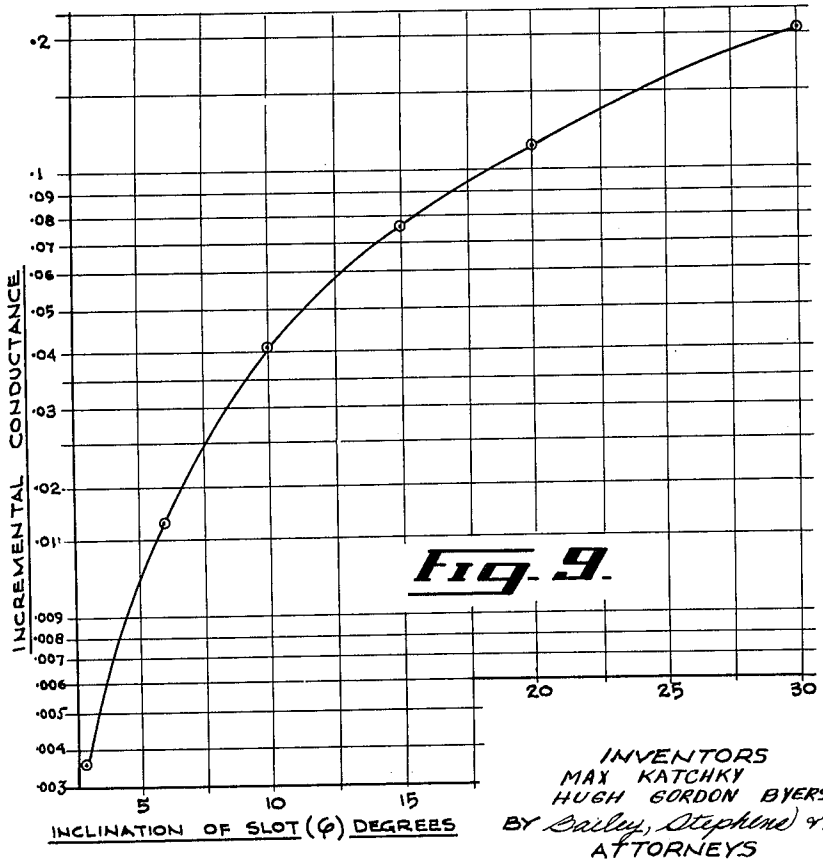


Fig. 9.

INVENTORS
MAX KATCHKY
HUGH GORDON BYERS
BY Bailey, Stephens & Huettig
ATTORNEYS

United States Patent Office 2,730,717
Patented Jan. 10, 1956

2,730,717

DIRECTIONAL WAVE ANTENNA FOR MARINE RADAR USE

Max Katchky and Hugh Gordon Byers, Toronto, Ontario, Canada

Application January 16, 1952, Serial No. 266,656

Claims priority, application Canada April 18, 1951

5 Claims. (Cl. 343—756)

This invention relates to directive antennas and in particular to a radar antenna for coastal and marine installation.

It is the object of this invention to provide a directive antenna which has better azimuth discrimination or a narrower horizontal beamwidth for the wind and weight loading on the antenna than is present in antennas used at this date.

It is the object of this invention to provide a directive antenna which has a larger vertical beamwidth than is practically possible with other designs.

It is the object of this invention to provide a directive antenna with very few critical tolerances, so that construction is facile and economical.

It is the object of this invention to provide a directive antenna design which can be adapted to supply different conditions of vertical and horizontal beamwidth by simple structural alterations.

The radar antennae in common use have truncated parabolic reflectors with a dipole or waveguide horn feed. This antenna as developed both during the war and since, has suffered from several serious disadvantages. It has been found that the tolerances for reflector curvature and for the position of the horn feed, in order to meet the functional requirements of narrow beamwidth and low side lobe level, are extremely critical, so that adjustment is required for each individual horn and feed assembly to ensure adequate operation, while the precise adjustment required, means that the assembly is very vulnerable to damage during installation. This type of antenna assembly also suffers from disadvantages in the antenna pattern produced. Although the radiation pattern of the parabolic antenna is good, difficulty has been encountered with wide angle and back radiation which can never be completely suppressed and which causes false echoes when the antenna is near relatively massive, or highly reflective, land targets. With such antennae, also, there is a lack of clarity and ability to discriminate, in the radar picture. This discrimination or clarity, and also the gain of the antenna, is proportional to the directivity of the radiation pattern, which in turn is dependent on the dimensions of the antenna.

With parabolic reflectors, practical considerations (weight, size and shape) have set a lower limit between half-power points in the radar pattern, which in the ship-borne sets is about 2°.

A further limitation of the parabolic reflector antenna is the low practical limit on maximum vertical beamwidth. In marine installations this is about 20° at ½ power and with ship installations where a large roll, due to heavy seas, is encountered, this is a distinct disadvantage.

There has now been developed, to overcome these disadvantages, an antenna assembly which combines and utilizes a linear array of radiating elements to form a horizontal pattern and a sectoral horn having diverging upper and lower walls (which are parallel to the longitudinal direction of the linear array) to shape the vertical polar diagram for optimum coverage.

The horizontal array is embodied in a length of rectangular waveguide with one side having slots cut therein, at regular intervals, situated at the throat of the horn. The waveguide is so oriented that the face of the waveguide, having the slots therein is substantially perpendicular to the plane which bisects the angle between the diverging upper and lower faces of the horn and is so oriented that the slotted face is nearest the mouth of the horn.

The waveguide slots may be vertical (slightly slanted) slots cut in the narrow side of the waveguide, whereby the radiation will be horizontally polarized or may be horizontal slots cut in the wide side of the waveguide so that vertically polarized radiation will be obtained. The arrangement may be selected to supply the type of radiation desired for any particular purpose. Similarly the type of array feed used with the guide will depend on the radiation characteristics desired and includes centre and end feeds for resonant and non-resonant arrays.

In marine installations for which this antenna may be used, horizontally polarized radiation is preferred. For this reason vertical slots cut in the narrow side of the waveguide are dealt with hereafter. The waveguide slot spacing and the frequency fed to the guide, are so adapted that the array is non-resonant.

The waveguide slots are alternately inclined (for reasons discussed hereafter) and the waveguide is so oriented that the slotted side faces the mouth of the horn, and is substantially perpendicular to the intended (maximum) direction of the radiated beam. This combination allows a very compact unit which requires considerably less space than a parabolic reflector antenna with the same vertical and horizontal beamwidths. The aperture efficiency (which is the actual antenna gain divided by the theoretical maximum gain for a given aperture) is expressed by the formula

$$f=\frac{Go}{4\pi A/\lambda^2}$$

where:

f=aperture efficiency
Go=actual gain
A=aperture area
λ=wavelength

and is much higher in the antenna design disclosed herein. It follows that the wind and weight loading, on the mounting and scanning rotation mechanism, is much less than with a parabolic reflector antenna with the same bearing discrimination (bearing discrimination being proportional to horizontal beamwidth). Conversely, an antenna, as disclosed herein, designed to give the same wind and weight loading on the mounting and mechanism, gives better bearing discrimination, than conventional parabolic antennae.

It should also be pointed out that the above-discussed advantages of wind loading refer to the overall wind resistance when the antennas under comparison are at the same angle to the wind direction. Such a wind loading tends to shear the antenna from its mounting and the antenna support must be designed with this stress in mind. However there is another wind load on the antenna and support, which is at least as important, and this is the wind load which tends to assist or retard rotation. The antenna having been designed to incur as little shear wind load as possible should then be designed to give as little variation of turning moment with rotation as possible. This avoids erratic effects caused by the wind on the

smooth sweep of the antenna. The parabolic reflector antenna, due to its asymmetric shape, was susceptible to such erratic effects, a small change in the orientation of the antenna relative to the wind direction sometimes causing the wind to rotate the horn and reflector very rapidly or to halt rotation altogether.

Research dealing with the antennae designs which minimize such effects has been reported on page 7 of the Progress Report of the National Research Council Laboratories, for April, May, June 1949. This research showed that an antenna having a rectangular exterior gave the most constant wind resistance during sweep rotation. There is herein disclosed an antenna which incorporates a further advance over the old parabolic reflector antenna by utilizing such a shape, and as before pointed out this advantage is at least as important as that of reduced overall shear loading.

A further advantage accrues from the use of a slotted waveguide and from the fact that the array is non-resonant, which is, that a much wider band width is obtainable than with the former design. Also construction time and expense of this assembly is lessened since the dimensional tolerances are less stringent due to the use of the non-resonant array design. Wide angle radiation is greatly reduced over that in the parabolic antenna, and there is greater flexibility in beamwidth design. For example, it is possible to obtain vertical beamwidths at half power from 15° to 40° or more, with only minor changes in production design.

The above construction is conducive to easy and accurate machining, and as this is the only part of the construction on which the dimensions are critical, the production and inspection of this antenna is much cheaper than with the truncated parabolic reflector type.

A vertical grating of thin conducting plates is placed at the mouth of the horn and extends along the full length of the array. This grating attenuates, to a large degree, the vertical E component vector which is produced by the use of inclined slots.

The arrangement of the grating elements is governed by the fact that their center to center spacing must be less than $\lambda/2$ where λ is the wavelength. Larger spacings than this cause negligible attenuation of the undesired vertically-polarized radiation.

The non-resonant array is end-fed, and provides a wide band width from the aspects of both impedance match and pattern.

It should be pointed out that there are two factors affecting bandwidth which have been arbitrarily chosen for the purposes of the specific embodiment selected herein. The array may be resonant or non-resonant, the former being more efficient, the latter giving wider bandwidth. The array may be centre or end-fed, and again the former is more efficient and convenient while the latter supplies a wider bandwidth. For the marine antenna herein disclosed a large bandwidth is of prime importance and therefore a non-resonant, end-fed array is used.

Because it is a non-resonant array there is provided a matched termination for the other end of the waveguide. Although this matched termination absorbs some of the antenna power, the amount absorbed is approximately the same as that lost in the parabolic reflector due to wide angle radiation.

A large amplitude taper is used, so that close in side lobes are suppressed.

Non-resonant arrays produce a radiation whose medial direction is slightly different from the direction normal to the horn. (This difference of directions being commonly known as the angle of squint.) This is not a serious disadvantage, since bearing calibration and alignment of a heading marker are performed on fixed targets of known bearing. The change of squint angle with change of radiation wavelength is small and a correction factor may be applied to the readings to compensate for the change.

The invention will now be described in detail, and reference may be had to the attached drawings in which:

Figure 1 is a front view of the antenna with the grating partially broken away for clarity.

Figure 2 is a bottom view of the antenna.

Figure 3 is a vertical cross-section of the antenna along the line **3—3** of Figure 1.

Figure 4 is an enlarged view (relative to Figure 1) of the slotted waveguide construction.

Figure 5 shows a vertical cross-section of the matched termination for the waveguide shown in Figure 4.

Figure 6 is a graph of the required illumination amplitude.

Figure 7 is a plot of the conductance per slot against the number of slots spaced at half wavelength intervals along the guide.

Figure 8 is a graph relating slot conductance to position along the array.

Figure 9 is derived from Figure 7 and is a graph relating the slot inclination to the slot conductance.

Figures 10, 11*a* and 11*b* are graphs which are explanatory of the radiation phenomena occurring when inclined slots are used.

Figure 12 is a sketch to illustrate simple array theory.

Figure 13 shows the effect of the conducting grating on radiation.

Figures 7 and 9 are obtained from "Longitudinally Polarized Array of Slots," NRC, PRA–104, December 1943.

Figure 13 is obtained from "Gratings and Screens as Microwave Reflectors," Report 54–20 Massachusetts Institute of Technology, Radiation Laboratory.

The antenna comprises a slotted section of waveguide **10** placed at the throat of a flared horn **20**. A matched termination **30** is connected to one end of the waveguide **10** while to the other end is attached a feed section **40** which is connected to a transformer **50** mounted on the upper section of a rotating coupler. The array and horn combination is securely fixed in position in a casing **60**, which is adapted for mounting on the rotating coupler in the gear box. A vertical conducting grating **70** is placed at the horn aperture and connected to the casing **60**.

The waveguide **10** is end-fed and is designed to utilize a radiation having a wavelength of 3.2 cms. in free space. The wavelength in free space will be hereafter referred to as λo. The waveguide has a length of 126", outside dimensions of 1" x ½" and a wall thickness of .064". It is designed to supply a horizontal beamwidth of 0.7° at —3 db and a maximum side lobe level which is about 40 db down. The amplitude taper (which is the ratio of the field intensity at each end of the waveguide **10**, to that at the centre) is .125. The amount of power absorbed by the matched termination **30** is about 4% of the transmitter output.

The spacing for slots **11** is chosen as 200° or 1.013". The λg (wavelength in the guide) being 1.824" when λo is 3.20 cms. The slots **11** are alternating in inclination in order to change their phase difference, between adjacent slots **11**, from 200° to 20°. This phase spacing is arbitrarily chosen and is thought to be the best for the particular application which is herein shown, but it will be shown that phase spacings between 140° and 175° and between 185° and 220° may be used.

The means for calculating the above recited values will be described below:

The low side lobe level requirement can be met only by the use of a steep illumination taper along the aperture. The horizontal radiation pattern of an aperture with an illumination distribution that is constant in phase, and linearly tapered in amplitude, is given by the following formula:

$$E_\theta = \frac{2(1-k)(1-\cos\beta)}{\beta^2} + \frac{k\sin\beta}{\beta} \qquad (1)$$

where

E_θ=field intensity at a given distance and at an angle θ from the normal to the aperture

k=amplitude taper, i. e. the ratio of the field strength at the ends of the aperture to that of the centre. $k \leq I$

$\beta=\frac{2\pi a}{\lambda}\times\sin\theta$

$2a$=horizontal aperture dimension

λ=wavelength

θ=angle of azimuth

as shown in "Relation Between Directional Diagrams and the Field Distribution Over the Aperture of a Radiator," by J. P. Ryan, CSIR Australia.

The above function is plotted for various values of k, the required amplitude taper and array length then being determined to meet the specification on beamwidth and side lobe level. For the desired conditions in this embodiment, namely: a 0.7° beamwidth at half-power and a side lobe level at least 40 db down from the peak, it is necessary to use an aperture length of 126" and a value of k=.125.

The required illumination amplitude distribution along the waveguide is shown in Figure 6, "x" being the displacement along the waveguide, "a" being the waveguide length and "b" being the field intensity at the ends of the waveguide.

The following equations relate the field intensity at a displacement x from one end of the guide to the displacement x.

$$E_{(x)}=b\left(1+7\frac{x}{a}\right) \qquad o<x<a \qquad (2)$$

$$=b\left(15-7\frac{x}{a}\right) \qquad a<x<2a \qquad (3)$$

The power function along the aperture is the square of the above,

$$Pr_{(x)}=c\left(1+7\frac{x}{a}\right)^2 \qquad o<x<a \qquad (4)$$

$$=c\left(15-7\frac{x}{a}\right)^2 \qquad o<x<2a \qquad (5)$$

$$(c=b^2)$$

Pr is the power radiated per unit length.

The normalized conductance per unit length (here designated $Go(x)$) is related to the displacement x by the following equations (treated in Non-Resonant Arrays, R. E. Bell, National Research Council, PRA–128, May 1945) and assuming that the matched termination 30 at the end of the waveguide 10 absorbs 4% of the input power:

$$Go(x)=\frac{.0197}{a}\frac{\left(1+7\frac{x}{a}\right)^2}{1-.0197\frac{x}{a}-.1381\left(\frac{x}{a}\right)^2-.3222\left(\frac{x}{a}\right)^3} \quad o<x<a \qquad (6)$$

$$=\frac{.0197}{a}\frac{\left(15-7\frac{x}{a}\right)^2}{3.209-4.438\frac{x}{a}+2.071\left(\frac{x}{a}\right)^2-.3222\left(\frac{x}{a}\right)^3} \quad a<x<2a \qquad (7)$$

Equations 6 and 7 apply to a continuous illumination function across the aperture. In the case of discrete radiators spaced less than a wavelength apart, it is possible to convert the formula, without appreciable error, as follows:

(*a*) Replace $2a$, the total length of the array, by N, the total number of radiators.

(*b*) Replace x, the distance along the array, by η, the number of the radiators under consideration.

(*c*) Replace $Go(x)$ by $G\eta$, the conductance of the ηth slot.

The curve in Fig. 9 shows the variation of $G\eta N$ with η/N. The number of slots required is determined by the array length and the choice of spacing between slots. A satisfactory slot spacing is 200° or 1.031" (λg for 1" x ½" O. D. waveguide with .064" wall thickness is 1.824" at λo=3.20 cms.). For ease in production, the slots are divided into 14 groups with 9 slots in each group, and the conductance $G\eta$ of the centre slot in each group is applied to all the slots in the group under consideration.

It will be understood that this method of approximating the proper slot inclination is arbitrary, and that the same method could be applied to other groups of other numbers of slots or that, if a precise array were desired, each slot could be machined at its calculated angle of inclination.

The required angle of slot inclination at a given point along the array is determined by (*a*) the necessary value of conductance at that point along the array determined by Equations 6 and 7, and (*b*) the angle of slot inclination which produces the necessary value of conductance. A mathematical expression for the value of slot conductance in terms of the angle of inclination does not adequately take into account the effects of mutual interaction between slots. For this reason, empirical data must be used to determine the required angles of inclination.

The graphs in Figs. 7 and 9 are the result of measurements made at λo=3.20 cms. in waveguide having dimensions of 1" x ½" O. D. and a wall thickness of .064" (any other size of guide for the same wavelength, or guides for different wavelengths, would require a different set of experimental curves similar to those in Figs. 7 and 9 before a slotted waveguide array could be designed). Fig. 7 is a plot of the conductance per slot against the number of slots spaced at half-wavelength intervals in the waveguide, each slot having the same angle of inclination with the slopes of adjacent slots being in opposite directions.

This curve shows the large effect of mutual interaction and also the limiting value (commonly called incremental conductance) attained with a large number of slots as is the case in a long array. The horizontal array disclosed herein is designed to operate on the limiting value or level portion of the curve shown at L—L of Figure 7. The curve is obtained by measuring the conductance (by the well-known standing wave ratio method) of groups of slots of one, two, three, four, etc. in number cut in the size of guide to be used. Each slot in the group is made to have the same angle of inclination and slots are spaced $\lambda g/2$ apart with alternate reversal of slope. A shorting plate is spaced $\lambda g/4$ from the last slot in the group. A number of curves (each for a different angle of inclination) similar to that in Fig. 7 are obtained experimentally, and the limiting value in each case is used to plot the curve in Fig. 9. The same experimental work must be repeated for different waveguide sizes and/or different wavelength bands.

Figure 4 is a sketch of the slotted waveguide construction. The alternate reversal of inclination is necessary to change the phase difference between adjacent slots from 200° to 20°. Due to this phase lag along the array, the plane of constant phase is displaced by an

$$\text{angle } \phi=\sin^{-1}\left[\frac{\lambda o}{\lambda g}-\frac{\lambda o}{\lambda s}\right]$$

where s=spacing between slots. This works out to angles of 4.3° and 3.75° at wavelengths of 3.19 and 3.21 cms. respectively.

The theory of cross-polarized lobes, and the operation of the alternately inclined slotted waveguide, is shown in Figure 10 which illustrates the current flow in the narrow

side of the waveguide at a given instant. The vectors E_1 and E_2 represent the polarity at a given instant of the electric potential produced by the slots cutting the lines of current flow. These vectors can be resolved into their horizontal and vertical components shown in Figures 11*a* and 11*b*.

This illustrates the manner in which the horizontally polarized components are brought into phase by alternate reversal of the slot inclination. With the non-resonant array, where the separation is slightly less or greater than $\lambda g/2$ there is a time phase difference between E_{1H} and E_{2H} which causes the squint angle. It is also evident that the vertically polarized components E_{1v} and E_{2v} are 200° out of phase so that there is no vertically polarized radiation at right angles to the array.

However, these components produce lobes at other angles, as shown in the following résumé of array theory. Reference should be had to Figure 12.

Elements 1, 2, 3, are discrete radiators in the array, and each is assumed to have an omnidirectional pattern. (Any directivity would modify the following results.) Let phase difference between slots be φ. Obviously

$$\phi=\frac{2\pi s}{\lambda g} \tag{1}$$

For an equiphase front (condition for major maxima), the length l must be such that the radiation from 2 is in phase with that from 3, and also radiation from 1 will be in phase with 2 and 3.

For this to be true

$$\frac{2\pi l}{\lambda o}=2\epsilon\pi-\phi \text{ for } \theta-Ve \tag{2}$$

$$\frac{2\pi l}{\lambda o}=2\epsilon\pi+\phi \text{ for } \theta+Ve \tag{3}$$

where $\eta=0, 1, 2, 3$, etc.

From (2)

$$\frac{l}{\lambda o}=\epsilon-\frac{\phi}{2\pi}=\epsilon-\frac{s}{\lambda g}=s\left(\frac{\epsilon}{s}-\frac{1}{\lambda g}\right) \tag{4}$$

$$\theta=\sin^{-1}\left(\frac{\epsilon\lambda o}{s}-\frac{\lambda o}{\lambda g}\right)$$

Similarly from (3)

$$\theta=\sin^{-1}\left(\frac{\epsilon\lambda o}{s}+\frac{\lambda o}{\lambda g}\right) \tag{5}$$

In the design described in this report,

$$s=\frac{20}{36}\lambda g$$

$\lambda g=1.824''$ and $\lambda o=1.260''$.

$$\therefore\theta(-ve)=33.5° \text{ for } n=1$$

(no lobe possible for $n=2$ or more)

and

$$\theta(+ve)=43.8° \text{ for } n=0$$

(no lobe possible for $n=1$ or more)

This indicates that only two lobes will exist in the pattern, one at +43.8° (feed side), the other at −33.5° (termination side) from the normal to the array. These figures check fairly well with the measured values of +44.5° and −34.5° respectively.

In the above analysis, the phase angle φ is the time phase displacement between slots, and this applies to the vertically polarized components. When there is also a space phase displacement of 180° due to the reversal of the slot inclination (as in the case of the horizontal components), the above expressions become

$$\phi=\frac{2\pi s}{\lambda g}-\pi \tag{6}$$

$$\theta(-ve)=\sin^{-1}\left(\frac{\lambda o(2n-1)}{2s}-\frac{\lambda o}{\lambda g}\right) \tag{7}$$

$$\theta(+ve)=\sin^{-1}\left(\frac{\lambda o(2n-1)}{2s}+\frac{\lambda o}{\lambda g}\right) \tag{8}$$

Again, for

$$s=\frac{20}{36}\lambda g$$

$\lambda g=1.824''$ and $\lambda o=1.260''$ the only possible lobe is that when $\eta=0$ and $\theta(+ve)=3.96°$, i. e.

$$\theta=\sin^{-1}\left(\frac{\lambda o}{\lambda g}-\frac{\lambda o}{2s}\right) \tag{9}$$

which is the well-known expression for the angle of the main beam.

The factors limiting slot spacing will now be discussed. It can be shown from Equations 7 and 8 that the slot spacing must be less than

$$\frac{3}{2}\frac{\lambda o\lambda g}{\lambda o+\lambda g} \tag{a}$$

or less than

$$\frac{1}{2}\frac{\lambda g\lambda o}{\lambda g-\lambda o} \tag{b}$$

whichever be smaller, to prevent the appearance of high level side lobes. That is, the spacing must be somewhat greater than 180° but less than the least value determined by the above expressions. This value will vary depending upon the wavelength and the waveguide size, which determines the waveguide wavelength according to the relation

$$\lambda g=\frac{\lambda o}{\sqrt{1-\left(\frac{\lambda o}{\lambda a}\right)^2}}$$

where a is the inside dimension of the wide side. In most cases waveguide dimensions are such that $\lambda o=7\lambda g$. Thus from (*a*)

$$s<\frac{3}{2}\frac{.7\lambda g^2}{1.7\lambda g}$$

$$<.62\lambda g$$

$$<223°$$

from (*b*)

$$s<\frac{1}{2}\frac{7\lambda g^2}{.3\lambda g}$$

$$<1.17\lambda g$$

Thus we can safely say that the spacing can vary between 185°–220° and 175° or less on the other side. In the region 175° to 185°, the design is too close to resonance to have sufficient bandwidth. There is no theoretical limit on the spacing less than 175° that can be used. However, too small a spacing has numerous disadvantages. It requires appreciably more slots for a given beamwidth, thereby increasing the cost. Mutual interaction between slots is greatly increased and an exact design becomes extremely difficult. For slot spacings less than 160°, new design curves similar to those in Fig. 7 must be obtained experimentally. Thus a practical lower limit is about 140°.

The squint angle inherent in non-resonant array antennas (that is the angle between the direction normal to the slotted waveguide face and the direction of maximum radiation) is not a disadvantage because bearing calibration and alignment of the antenna is done individually on a target of known bearing. The change in this angle, in the specific embodiment described above, is a very small, only 0.55° from 3.19 cms. to 3.21 cms., and in applications where this deviation is important, a correction factor depending on the wavelength supplied, can be applied to the bearing calibration.

The waveguide is usually made of brass although there is no necessary restriction to this material and the scope of usable material is obvious to anyone who is familiar with waveguides.

The waveguide **10** has its slots **11** individually covered with thin (.008") strips of Vinylite material **12**, which

is bonded to the waveguide **10**, using cement of such a type as that known as EC847 Cement made by Canadian Durex Abrasives. The weathering and aging effects (both electrical and physical) on the Vinylite and cement bond have been fully investigated and the covering was considered satisfactory for use under all practical conditions.

The horn **20** may be formed of steel or other metal but is preferably made of anodized aluminum to decrease the weight. It is formed of two divergent plates **21** which are symmetrical about a horizontal plane. These plates were selected to have a flare angle of 30° as the best compromise to keep the size of the horn within practical limits. This angle may be used with a large range of vertical beamwidths (i. e. from 15° to 25° and possibly even greater at half power) by changing the horn length and hence the aperture.

The divergent plates **21** are made parallel in the vicinity of the waveguide and a spacing strip **23** is clamped between the rear end of the horn and waveguide to provide a quarter-wavelength choke to eliminate back radiation. Clamping springs **24** are provided for this purpose. On the narrow face of the waveguide are several fixing studs **26** which pass through the clamping spring **24** and secure these and the waveguide to the rear wall of the casing by means of a nut **25**. Spacing washers **27** are used to adjust the waveguide to obtain the straightness and parallelism to the casing of the slotted front narrow face. The tolerance for this adjustment is $\frac{1}{16}''$.

The outer extremity of each of the divergent plates **21** consists of a contiguously extending vertical, then horizontal portion **22**. This portion is for the purpose of conjoining the casing **60** to the horn **20** which will be hereinafter described.

The conducting edgewise grating **70** is mounted at the horn aperture and comprises thin vertical plates **71**. These plates are, in this embodiment, .020" thick, $\frac{5}{8}''$ deep and are spaced $\frac{1}{2}''$ apart the plates being oriented so that their edges face inwardly and outwardly relative to the horn and the $\frac{5}{8}''$ sides are parallel to the direction of radiation. The spacing and depth of the plates is designed to sufficiently attenuate the cross polarized radiation without appreciably lowering the intensity of the horizontally polarized beam and it will be noted that the centre to centre spacing of .500" is less than half the radiation wavelength as discussed in column 3 line 42 herein. The design was based on information contained in the publication "Gratings and Screens as Microwave Reflectors, M. I. T. Radiation Laboratory Report #54–20" and the edgewise grating was found to have the least effect on horizontally polarized radiation while attenuating the vertically polarized radiation. In Figure 13 is shown the relationship between the transmission of the (undesirable) vertically polarized radiation and the percent open area of the horn mouth. In this embodiment the centre to centre spacing in wavelengths is .397 and the strip depth in wavelengths is .496. It will be seen from reference to Figure 12 that the transmission factor is approximately 1%.

It should be pointed out that the graph was drawn for a grating having a plate thickness in wavelengths of .0175 whereas in this embodiment the plates have a thickness of .0159λ. There is however a negligible difference in the transmission factor for small changes (±.005").

The efficiency of the grating in reducing cross-polarized radiation has been checked and measurements indicated the substantial elimination of the vertically-polarized lobes at ±40° from the normal to the antenna. (Less than 1% in field intensity being allowed to pass.) Without the grating, the amplitude of the lobes at these angles was found to be about 17–20% in voltage. With normal (horizontal) polarization, small lobes about 3% in voltage were found at the angles where the cross-polarized lobes occur, and the grating had negligible effect on the amplitude of these lobes. As they are small in amplitude and very narrow in azimuthal angle, the possibility of false echo trouble is much less than with the parabolic reflector where the wide-angle radiation lobes are very wide in both azimuth and elevation.

To protect the assembly from snow and ice, a window **63** made of .060" Vinylite is placed across the full antenna aperture. Measurements have indicated that this thickness of Vinylite causes negligible reflection or attenuation. The window need not be made airtight since the waveguide slots are covered with strips of Vinylite, as before described.

Shown in Figure 5 is the matched termination **30** which absorbs 4% of the antenna power and is preferably made of polyiron. It is built to have a low moisture absorption property and at the same time is sufficiently rugged to stand reasonable vibration and shock. This termination eliminates the large side lobe which would otherwise appear in the radiation pattern due to the fact that reflected energy from the end of the array is radiated by the antenna at an angle equal and opposite to the squint angle. To keep the overall length down to a minimum, a short taper is cut in the polyiron and a good match is obtained by putting three tuning screws **31** in the broad face of the waveguide. After being adjusted, the screws are soldered in place and the match over the band is found to be sufficiently good. A Vinylite window (not shown) is bonded across the end of the waveguide containing the polyiron and the unit is bolted to the array using a conventional choke-flange coupling.

Measurements were made on the antenna to determine the fraction of power lost in the matched termination. In all cases, there was close agreement with the design value of 4%.

The antenna is mounted on a standard gear box (not shown), the waveguide **40** being extended from a transformer **50** on the rotating joint, to the feed end of the guide. The array is joined to the waveguide feed by a curved section or "shepherd's crook" **81**.

The casing **60** is a necessary element to protect the antenna from the weather and to provide a mounting means. The casing described below is only one of many designs which could be used and the description to follow is not intended to be limiting, but merely to show a possible method.

The casing is of general rectangular shape, having a length slightly greater than the length of the array and termination, a depth substantially the same as the depth of the horn, and a height greater than the height of the horn. The casing is closed on all faces but the front, which has an opening **61** approximately equal to the area of the horn mouth, said opening being approximately symmetrically disposed vertically on the casing front. The upper and lower edges of the opening have out-turned flanges **62** to which are bolted rectangular U-shaped channels **63** running the length of the array, the open face of the U being vertical and towards the opening **61**. In these channels are seated rectangular portions **22** of the outer horn extremity. These portions are each seated against the inner vertical and lower wall of the channel. The upper and lower extremities of the thin grating plates **71** and the upper and lower edges of the Vinylite window **63** respectively contact the inner upper and inner lower surfaces of the respective channels **63**. Running the full length of the waveguide is a rod situated in the approximate centre of each U-shaped channel **63**, the rod being maintained in this position by its rigid attachment to casing members. Each of the grating plates **71** has corresponding holes near its upper and lower extremities the holes being so located that when each plate is seated in the channels **63** the rod and the holes correspond. The plates are thus threaded onto the rods and their spacing is maintained by hollow spacing elements **64** threaded on

the rods between plates **71**. Nuts or other forms of screw connection (not shown) hold the arrangement of plates and spacers in proper relationship. There is a certain amount of the inner width of the channels which is not filled when rectangular portions **22**, plates **71** and Vinylite window **63** are seated therein as described herein. This space is filled and the assembly fixed in position by filler strips **65** which run the full length of the array.

These filler strips are pressed into place after portions **22**, plates **71** and spacing members **64** are in place in the U-shaped channel member. Waterproof, weatherproof cement is coated about the filler strips before insertion, and after insertion, surplus cement is wiped off the Vinylite window and the channel edge.

The first experimental prototype was tested and these tests indicated that its characteristics were very close to the values predicted in the design. The horizontal beamwidth was found to be 0.7° at half-power while the vertical beamwidth ranged from 16.0° at half-power for a horn of 4¼" to 25° at half-power for a 3⅛" aperture. The experimental horn was constructed of wood lined with copper foil, and had a flare angle of 30°. Changes in aperture dimension were made by simply cutting off part of the horn. Larger apertures than 4¼" caused a widening of the pattern, thus narrower vertical beamwidth can be obtained only by using a smaller flare angle and therefore a much longer horn. The position of the array at the throat of the horn was varied over a small range until the best horizontal pattern was obtained. No change in horizontal pattern was noted with variations in the vertical pattern.

Two additional experimental arrays of shorter length were designed and built. One was 66" long and had a horizontal beamwidth of 1.35° at half-power, the other was 82" long and had a 1.1° beamwidth at half-power.

The first production prototype was designed to have a 0.7° horizontal beamwidth and a 16.0° vertical beamwidth. The application suggested for this antenna was for land based coastal radar. A second unit was designed to have a 1.1° beam at half-power in the horizontal plane with a 25° beam at half-power in the vertical. The wider vertical beamwidth was considered necessary to provide sufficient coverage for ships with a heavy roll in rough stormy weather.

It will be understood that the method of mounting the waveguide in the casing is not limiting but merely constitutes the best method known to the inventor.

Similarly the specific details of the grating, listed in column 9, lines 61–65, and of the matched termination described in column 10, lines 13–30, herein are those which are thought best for the invention as described in the illustrative embodiment and are not intended to limit the invention as claimed.

We claim:

1. An antenna assembly comprising a sectoral horn, a slotted waveguide of rectangular cross-section and so positioned at the throat of said horn that the radiating face of said waveguide is directed towards the mouth of said horn in the plane bisecting the angle of divergence of the walls of said horn, said radiating face being one of the narrow sides of said waveguide, said narrow side having regularly spaced, alternately inclined slots cut therein, means for end-feeding said waveguide with power at a frequency to which the spacing of said slots is non-resonant, and means for filtering the energy radiated from said waveguide and reflecting back into said waveguide unwanted vertically-polarized energy radiated therefrom.

2. An antenna assembly comprising a sectoral horn, a horizontal slotted waveguide so positioned at the throat of said horn that the radiating face of said waveguide is directed towards the mouth of said horn in the plane bisecting the angle of divergence of the walls of said horn, means for end-feeding said waveguide, and a vertical filter grating of thin, elongated, electrically-conducting plates at the mouth of said horn, said plates reflecting back into said waveguide unwanted vertically-polarized radiation and being normal to the plane bisecting said angle of divergence, the longitudinal axes of said plates being vertical and the broad faces of said plates being at right angles to the vertical plane longitudinally bisecting said waveguide.

3. An antenna assembly comprising a sectoral horn, a horizontal slotted waveguide of rectangular cross-section and so positioned at the throat of said horn that the radiating face of said waveguide is directed towards the mouth of said horn in the plane bisecting the angle of divergence of the walls of said horn, said radiating face being one of the narrow sides of said waveguide, said narrow side having regularly spaced, alternately inclined slots cut therein, said waveguide being end-fed with power at a frequency to which the spacing of the slots is non-resonant, and a vertical filter grating of thin, elongated, electrically-conducting plates at the mouth of said horn, said plates reflecting back into said waveguide unwanted vertically-polarized radiation and being normal to the plane bisecting said angle of divergence, the longitudinal axes of said plates being vertical and the broad faces of said plates being at right angles to the vertical plane longitudinally bisecting said waveguide.

4. An antenna assembly comprising a sectoral horn, a horizontal slotted waveguide of rectangular cross-section and so positioned at the throat of said horn that the radiating face of said waveguide is directed towards the mouth of said horn in the plane bisecting the angle of divergence of the walls of said horn, said radiating face being one of the narrow sides of said waveguide, said narrow side having regularly spaced, alternately inclined slots cut therein, means for end-feeding said waveguide with power at a frequency to which the spacing of said slots is non-resonant, and a vertical filter grating of thin, elongated, electrically-conducting plates at the mouth of said horn, said plates reflecting back into said waveguide unwanted vertically-polarized radiation and being normal to the plane which bisects said angle of divergence, the longitudinal axes of said plates being vertical and the broad faces of said plates being at right angles to the vertical plane longitudinally bisecting said waveguide, the centre to centre spacing of said plates being less than half the free space wave length of the electromagnetic radiation from said waveguide.

5. An antenna assembly comprising a sectoral horn, a horizontal slotted waveguide of rectangular cross-section and so positioned at the throat of said horn that the radiating face of said waveguide is directed towards the mouth of said horn in the plane bisecting the angle of divergence of the walls of said horn, said radiating face being one of the narrow sides of said waveguide, said narrow sides having regularly spaced, alternately inclined slots cut therein, means for end-feeding said waveguide with power at a frequency to which the spacing of said slots is non-resonant, and a vertical filter grating of thin, elongated, electrically-conducting plates at the mouth of said horn, said plates reflecting back into said waveguide unwanted vertically-polarized radiation and being normal to the plane which bisects said angle of divergence, the longitudinal axes of said plates being vertical and the broad faces of said plates being at right angles to the vertical plane longitudinally bisecting said waveguide, the centre to centre spacing of said plates being less than half the free space wave length of the electromagnetic radiation from said waveguide, said antenna assembly being enclosed in a protective casing of rectangular cross-section, the side of said casing opposite said mouth of said horn being of a material allowing free transmission of electromagnetic radiation therethrough.

(References on following page)

References Cited in the file of this patent

UNITED STATES PATENTS

2,415,807	Barrow et al.	Feb. 18, 1947
2,470,016	Clapp	May 10, 1949
2,527,222	Iams	Oct. 24, 1950
2,573,746	Watson et al.	Nov. 6, 1951
2,608,656	Korman	Aug. 26, 1952
2,637,847	Affel, Jr. et al.	May 5, 1953

FOREIGN PATENTS

602,689	Great Britain	June 1, 1948
629,107	Great Britain	Sept. 13, 1949
642,825	Great Britain	Sept. 13, 1950

OTHER REFERENCES

Kees et al.: "Cavity Aircraft Antenna," Electronics (January 1947).