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(71) Applicant: **DECCA LIMITED**
Western Road
Bracknell Berkshire RG12 1RG(GB)

(72) Inventor: **Chua, Lye Whatt**
High Beeches Green Dene
East Horsley Surrey KT24 5RU(GB)

(74) Representative: **Cross, Rupert Edward Blount et al**
BOULT, WADE & TENNANT 27 Furnival Street
London EC4A 1PQ(GB)

(54) **Slotted waveguide antenna and array.**

(57) An antenna is formed with a hollow waveguide having a narrow slot in one face. A Vivaldi horn type radiator is mounted with a coupling arrangement to couple energy in the waveguide through the slot to the radiator. The slot can be a non-radiating longitudinal slot, parallel to the waveguide axis, and several radiators may be mounted in a non-resonant slot along the length of the waveguide to form a linear resonant array.

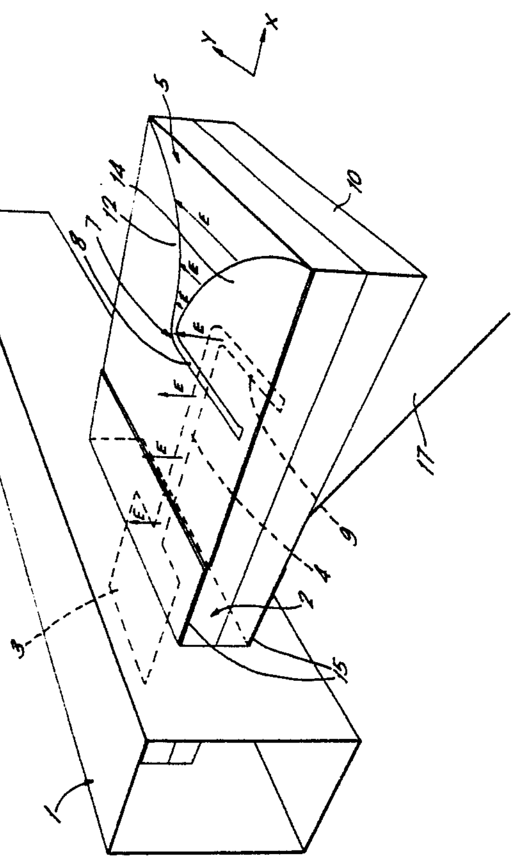

FIG 1.

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SLOTTED WAVEGUIDE ANTENNA AND ARRAY

This invention relates to slotted waveguide antennas and arrays and in particular to slotted waveguide antennas and arrays for use in microwave radars antennas and arrays.

It is a well known technique to cut slots into a waveguide wall in order to couple the internal field to space and constitute thereby an antenna: generally, the degree of coupling depends upon both the current density, associated with the boundary current sheet that is interrupted by the slot, and the component of the length of the slot transverse to the lines of current.

Consequently, a narrow slot cut along the centre of the broad face of a rectangular waveguide will constitute a non-radiating element since it lies substantially within a region of zero current density, whereas, when such a narrow slot is oriented at an angle to the waveguide axis it perturbs the current sheet and constitutes a radiating element.

It is also a well known technique to cut a series of radiating slots in a waveguide to form an antenna array. Commonly, inclined slots are cut in the narrow wall of a hollow rectangular waveguide when an array having a direction of polarisation of radiation that is parallel to the waveguide axis is desired. Such arrays, however, generate an unwanted component, orthogonal to the desired mode. Although, especially for small tilt angles, the proportion of power associated with unwanted modes compared to total radiated power is not large, it has nevertheless been found necessary to incorporate specific means for supressing the unwanted mode: electrically conducting strips or wires positioned at the array aperture to be parrallel to the E-field of the spurious mode are commonly used for this purpose.

A further problem with the inclined slot type of design is the necessity of accurately machining the slot to the desired angle of inclination: for instance, for a slot cut in the narrow face of a rectangular waveguide and inclined at an angle 0 to the normal to the waveguide axis, the slot conductance obeys the relation $g = g_o \mathrm{Cos}^2 \theta$: this results in the necessity of aligning slots to an accuracy of 0.1 degrees. The level of the unwanted side lobes is, for instance, critically dependent on such accuracy of alignment.

A further problem with known arrays is associated with the practise of utilising resonant slots: this requires the perimeter of any slot to be substantially equal to the wavelength of radiation utilised and imposes further demands on the accuracy required in machining the slot.

In accordance with the present invention, a slotted waveguide antenna comprises a hollow waveguide, an aperture defining a narrow slot in the waveguide, a Vivaldi horn type radiator and energy coupling means for coupling energy in the waveguide through the slot to the radiator.

The Vivaldi horn type radiator is a substantially planar slot-line aerial with constant beamwidth an theoretically unlimited instantaneous frequency bandwidth: more importantly, the radiated wave from a Vivaldi horn type radiator is linearly polarised in the plane of the aerial. The detailed structure and function of the Vivaldi horn type radiator is already known: for instance, reference may be made to UK-A-1601441 or to "The Vivaldi Aerial" (P.J. Gibson) pp101-105: Proc .9th EU M.C., Brighton, 1979. In general terms, however, the Vivaldi horn type radiator comprises a diverging slot line conductor pair on a dielectric constant, e.g. fibre glass, substrate.

The general form of the taper is given by

$[Y]^2 = K \exp (MX) + C$

where the x-axis is colinear with the axis of the radiator and directed towards the mouth of the radiator; C depends on the impedance of the feeding portion of slot line; and K and M are constants depending, respectively, on the length of the taper and the dielectric constant of the substrate.

The radiation mechanism can be generally understood to be a non-resonant travelling wave, the energy of which is gradually coupled to the radiation field as the separation between the slot line conductors increases. Further, the diverging slot-line structure provides the required gradual impedance match from that at the feeding portion of slot line to the free space impedance of 377 Ohms.

The use of a Vivaldi horn type radiator with a slotted waveguide thus entirely obviates the need for spurious mode suppression devices commonly used with inclined slot type antennas. Further, the requirement for both accurate alignment and, for non-resonant slots, accurate sizing, is also greatly reduced.

According to further features of the invention a slotted waveguide antenna comprises a hollow waveguide, an aperture defining a narrow slot in the waveguide, a Vivaldi horn type radiator and energy coupling means for coupling energy in the waveguide through the slot to the radiator and wherein the waveguide is a hollow rectangular waveguide and the slot is a non-radiating, longitudinal slot, parallel to the waveguide axis.

Embodiments of the invention will now be described with reference to the accompanying drawings in which:-

Figure 1 is a perspective view of a slotted waveguide antenna and array in accordance with the present invention,

Figure 2 is a cross-sectional view through a slotted waveguide antenna in accordance with the present invention and depiciting a balanced configuration of Vivaldi horn type radiators,

Figure 3 is a schematic plan view of a slotted waveguide array in accordance with the present invention and depicting an end fed configuration,

and Figure 4 is a plan view as in Figure 3 but depicting a centre fed configuration.

In Figure 1, a portion of a hollow rectangular waveguide 1 is shown having a narrow longitudinal slot 2 positioned such that its long axis lies along the centre of one broad wall and is, therefore, parallel to the waveguide axis. It will be apparent that such a slot constitutes a non-radiating element for the dominant TE_{10}mode.

Consequently, a probe 3, extending through the slot 2 and into the interior of the waveguide is utilised to couple energy from the interior: it will be appreciated that the extent of coupling is dependent on the extent of penetration. The probe 3 is a substantially planar possible lithographically printed probe having a one or both surfaces bounded by a dielectric constant substrate 10 and forming a portion of a conductor of a strip transmission line 4. The substrate 10 may be extended to supportively contact the internal surface of the waveguide on a side facing the slot. A further advantage to sandwiching the probe 3 between dielectric layers 10 is that the antenna can be operated at relatively high power levels: for instance, at X-band, transmitter peak power levels in excess of 35 KW are possible. Alternatively, a probe may be inserted through the wall of the waveguide substantially adjacent to the slot in order to sufficiently perturb the internal current sheet to couple energy from an otherwise non-radiating slot.

The Vivaldi horn type radiator, shown generally at 5, has a slot line, feed portion 7 terminating in a first section of slot line 8 which is coplanar but perpendicular to the feed portion 8. The length of the first section 8 is $\lambda_g/4$ so that it constitutes an effective short circuit element. Lying parallel and below the first section 8 is an end section 9 of strip transmission line, also of length $\lambda_g/4$ but constituting an effective open circuit element: a dielectric medium 10, in this embodiment also serving as the high dielectric constant substrae of the Vivaldi horn type radiator 5, separates first section 8 from end section 9. These two sections comprise the transition element required to twist the E-field vector from perpendicular to parallel to the xy plane. The alignment of the E-field vector can be readily reversed by changing the orientation of the transition element, comprising sections 8 and 9.

In an alternative embodiment (not shown) the energy coupling means comprises a co-axial probe forming a portion of a co-axial transmission line, and a co-axial/slot transition element for coupling energy from the co-axial transmission line to the slot line of the Vivaldi type horn radiator.

The Vivaldi horn type radiator further comprises a symmetrical pair of diverging slot line conductors 12 and 14, defining the required exponential taper.

Referring now to Figure 2, a further Vivaldi horn type radiator 5 may be positioned parallel to a first radiator, the pair being positioned equidistantly from the line defining the long axis of the slot.

Such a symmetrical arrangement constitutes a balanced, as opposed to an unbalanced, radiator. The balanced arrangement generates a beam which is symmetrical about the xy plane, whereas a single radiator generates a tilted beam: the latter may, however, be advantageously utilised in, for instance, the reduction of sea clutter. Further, the balanced arrangement has a lower loss of radiation at the transition element but may be more complex to manufacture.

In addition, the beam pattern in the plane perpendicular to the xy plane is principally controlled by metal flares, the edge of one of which is indicated at 17.

In addition, the antenna incorporates flanges 15, bounding both outer long sides of the slot, and having a width of $\lambda_g/4$ to constitute an effective open circuit elements. Consequently, the ground lane current associated with the ground plane of strip transmission line 4 is inhibited from circulating on the outside walls of the waveguide 1: the Vivaldi horn type radiator 5 is, therefore, electrically isolated from the waveguide.

In Figure 3, six adjacent Vivaldi horn type radiators are depicted, each being associated with a non-resonant slot (not shown), the mid-point of adjacent slots being $\lambda_g/2$ apart. This arrangement constitutes, therefore, a linear, resonant array.

A radiation input 20 feeds the waveguide 1 from one end. In addition, the orientation of the transition elements, each comprising a section 8 and 9, alternates for adjacent Vivaldi radiators 5 in order to maintain a uniform phase front in the radiation field. A further advantage to this arrangement is the cancelling of the unwanted residual radiation of adjacent transmission elements near the axis of radiation.

Further, different probes 3 each have a predetermined extent of penetration into the waveguide 1 in order to provide a required amplitude taper across the width of the radiation profile. It will be apparent that the length of the array determines the beamwidth of the antenna array, and, consequently, the gain of the array. In addition , a matched termination 21 is provided for the waveguide.

In Figure 5, a radiation input 20 feeds the centre of a wavegude 1. The portions of waveguide to the left and right of the input 20 are offset such that L_1 -L_2 = $\lambda_g/4$. Consequently, conjugate impedance matching is achieved. However, in order to maintain a uniform phase front in the radiation field, the strip transmission line 4 associated with each Vivaldi radiator to the right of the input 20 is extended by an extra $\lambda_g/4$ at portion 18.

Claims

1. A slotted waveguide antenna comprising a hollow waveguide, an aperture defining a narrow slot in the waveguide, a Vivaldi horn type radiator and energy coupling means for coupling energy in the waveguide through the slot to the radiator.

2. A slotted waveguide antenna as claimed in Claim 1 wherein the waveguide is a hollow rectangular waveguide.

3. A slotted waveguide antenna as claimed in any preceding claim wherein the narrow slot is a longitudinal slot parallel to the waveguide axis.

4. A slotted waveguide antenna as claimed in any preceding claim wherein the narrow slot is positioned to constitute a non-radiating slot.

5. A slotted waveguide antenna as claimed in Claim 4 wherein the energy coupling means comprises a probe for insertion through the slot.

6. A slotted waveguide antenna as claimed in Claim 4 wherein the energy coupling means comprises a probe for insertion through the wall of the waveguide substantially adjacent to the slot.

7. A slotted waveguide antenna as claimed in Claim 5 wherein the energy coupling means comprises a substantially planar printed probe; a dielectric constant substrate bounding at least one of the surfaces of the printed probe, the probe forming a portion of a conductor of a strip transmission line, and a strip/slot transition element for coupling energy from the strip transmission line to the slot line of the Vivaldi type horn radiator.

8. A slotted waveguide antenna as claimed in Claim 5 wherein the energy coupling means comprises a co-axial probe forming a portion of a co-axial transmission line, and a co-axial/slot transition element for coupling energy from the co-axial transmission line to the slot line of the Vivaldi-type horn radiator.

9. A slotted waveguide antenna as claimed in Claim 7 wherein the transition element comprises a first section of slot line, coplanar and perpendicular to a feed section of slot line, the axis of the feed section being co-linear with the axis of the associated Vivaldi type horn radiator, and wherein the length of the first section is $\lambda_g/4$ to constitute an effective short circuit element; and an end section of the strip transmission line, parallel with the said first section of slot line and separated from it by a portion of a dielectric medium, and wherein the length of the end section is $\lambda_g/4$ to constitute an effective open circuit element.

10. A slotted waveguide antenna as claimed in Claim 9 wherein the said end section is orientated with respect to the slot line feed to provide an emitted wave of required spatial phase sense.

11. A slotted waveguide antenna as claimed in Claim 8 wherein the probe has a predetermined extent of penetration into the waveguide to provide a required magnitude of coupling of energy to the associated Vivaldi type horn radiator.

12. A slotted waveguide antenna as claimed in any preceding claim wherein a flange of width $\lambda_g/4$ bounds both outer long sides of the slot to constitute effective open circuit elements.

13. A slotted waveguide antenna as claimed in any preceding claim wherein the coupling means supportively contacts the internal surface of the waveguide on a side facing the said slot.

14. A slotted waveguide antenna as claimed in any preceding claim comprising a further Vivaldi horn type radiator positioned parallel to said first radiator, the pair being positioned equidstantly from the line defining the long axis of the slot.

15. A slotted waveguide antenna array comprising a plurality of slotted waveguide antennas as claimed in any preceeding claim, wherein the midpoint of adjacent slots are a distance $\lambda_g/2$ apart.

16. A slotted waveguide antenna array as claimed in Claim 15 wherein the array is an end-fed array.

17. A slotted waveguide antenna array as claimed in Claim 15 wherein the array is a centre-fed array.

18. A slotted waveguide antenna array as claimed in Claims 17 or 18 wherein different probes each have a predetermined extent of penetration into the waveguide to provide a required amplitude taper across the width of the radiation profile.

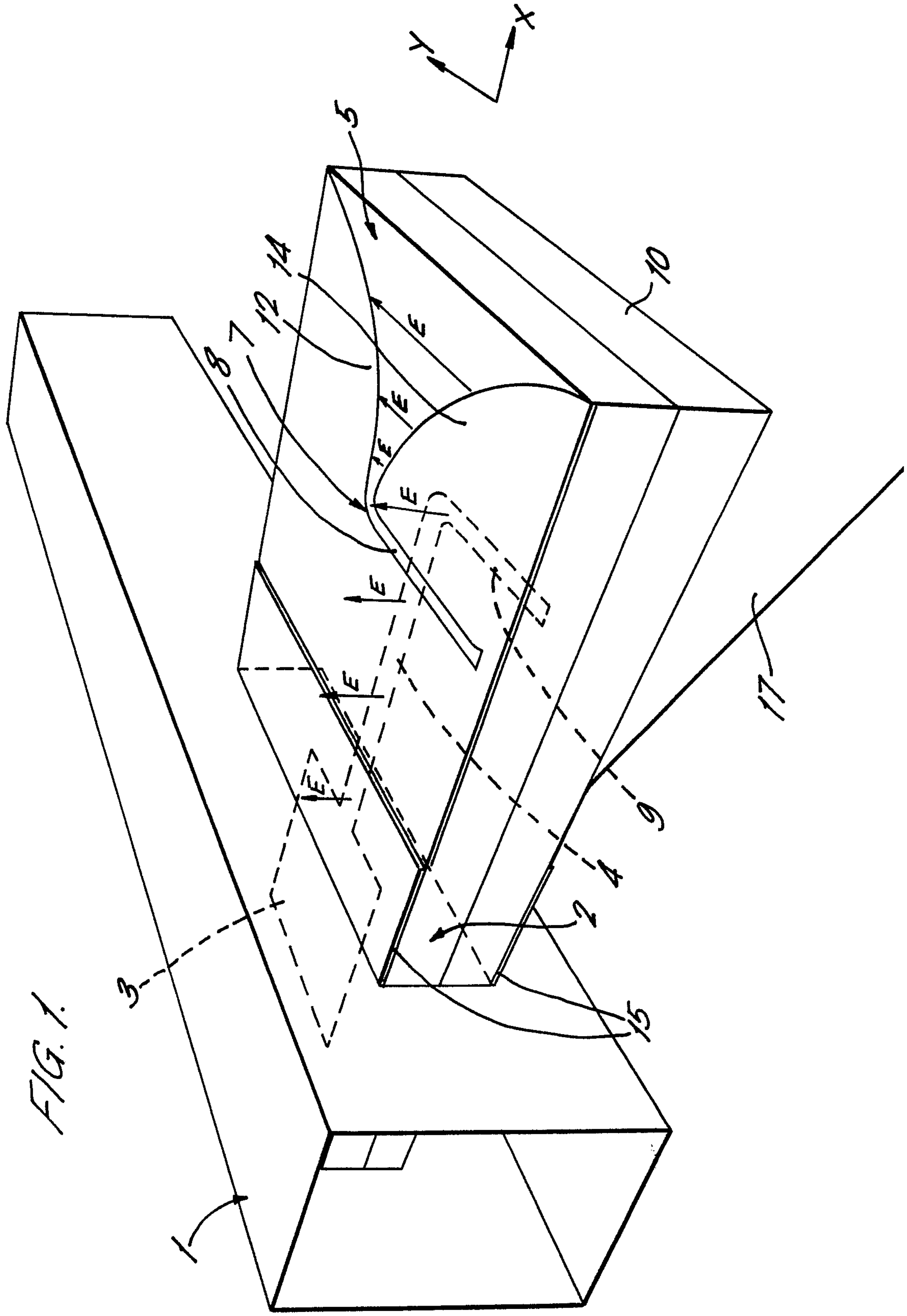

FIG. 1.

FIG. 2.

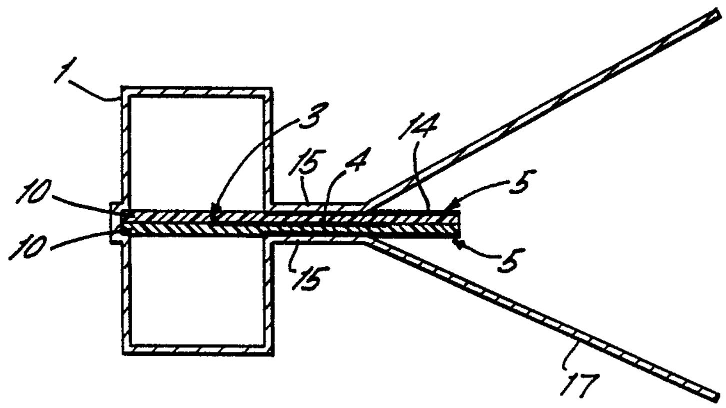

FIG. 3.

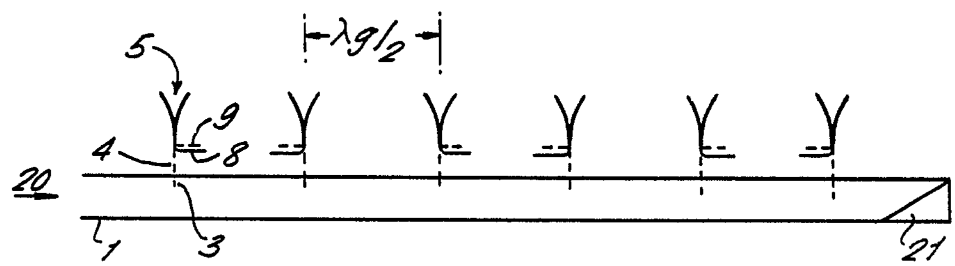

FIG. 4.