March 2, 1965 W. G. HEINARD ETAL 3,172,113

CURVED ANTENNA WITH VARIABLY SPACED SLOTS

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FIG. 1

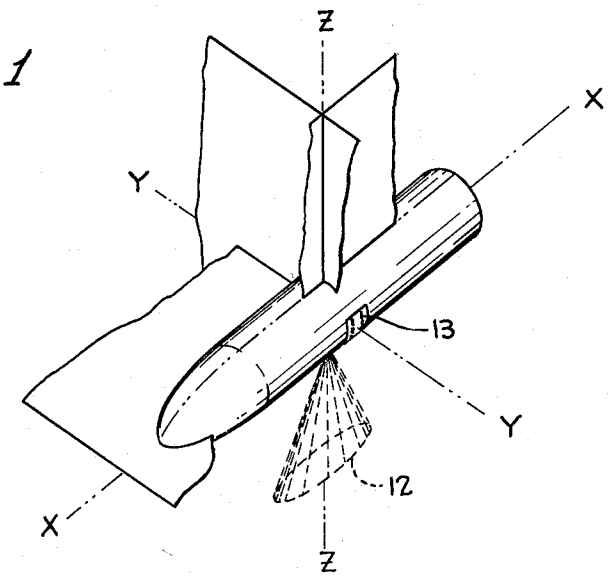


FIG. 2a

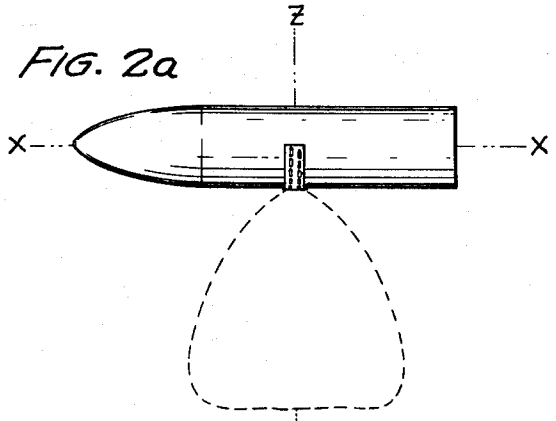


FIG. 2b

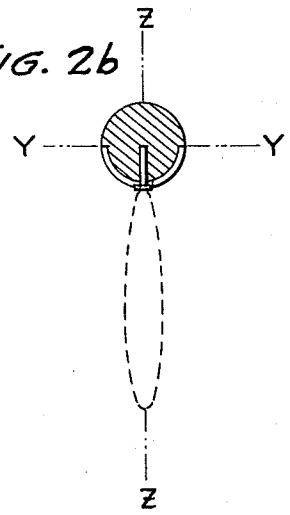
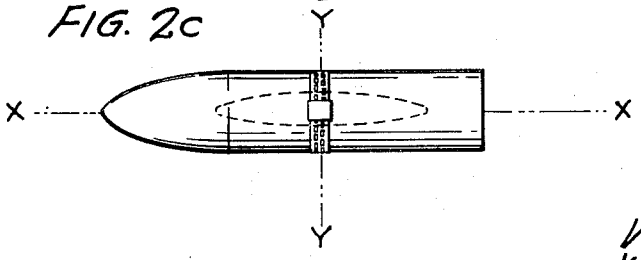


FIG. 2c



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FIG. 3

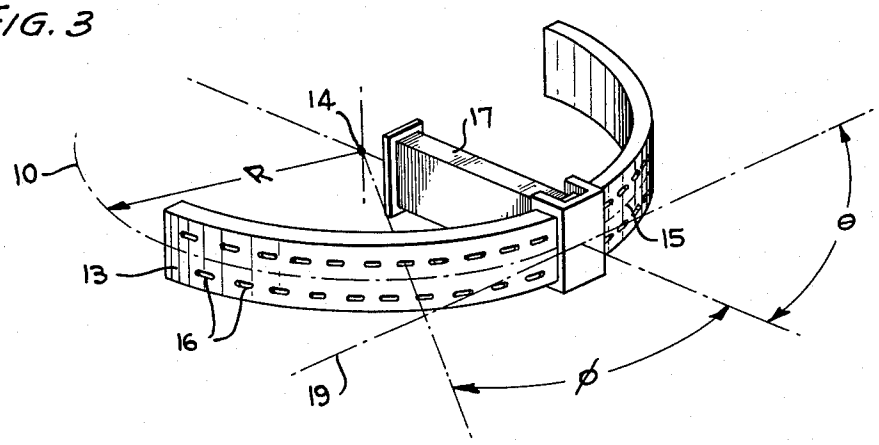
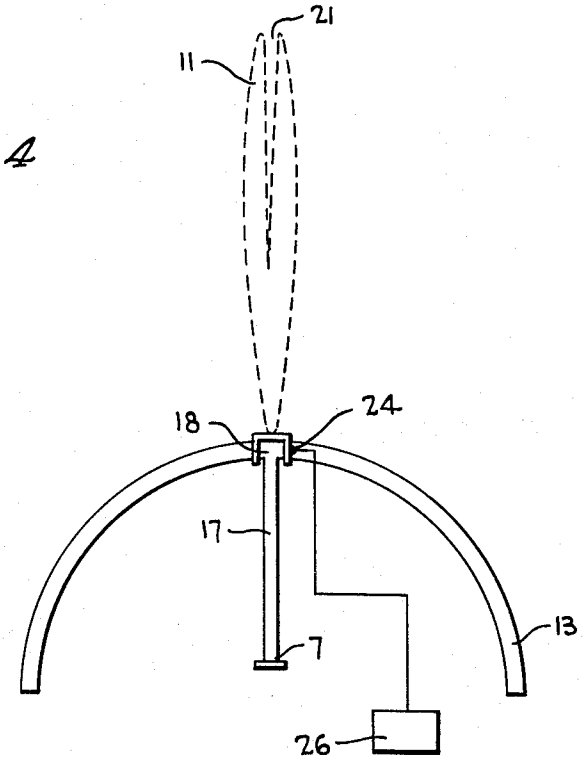


FIG. 4



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CURVED ANTENNA WITH VARIABLY SPACED SLOTS

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9 Claims. (Cl. 343—771)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment to us of any royalty thereon.

This invention relates to directional electromagnetic wave antennas, and more particularly to antennas which may be used on a moving vehicle without adverse influence on the vehicle's aerodynamic characteristics.

High speed aircraft and missiles have placed severe demands on electromagnetic radiating antennas. Along with space and weight considerations, these antennas must not only have directive radiation patterns but also be able to be incorporated within the existing air frame without producing an adverse effect on its flight characteristics. Slotted waveguide antennas are commonly used in such situations. These antennas are straight waveguide sections, having radiating slots in a broad face of the guide, and may be easily accommodated along a longitudinal axis of a cylindrical body, such as a missile. These antennas may be designed to have "fan" shaped radiation patterns in which the main lobe of the antenna lies substantially on a conical surface, with axis of the cone coinciding with the longitudinal axis of the waveguide. The planar radiation pattern is achieved by properly spacing the apertures in the waveguide and controlling their excitation. The degree to which the radiation can be limited to a single plane, or in other words the narrowness of the plane, is primarily determined by the physical length of the antenna.

Straight slotted waveguide antennas are satisfactory when it is desired to have a directive radiation pattern in a plane which intersects the longitudinal axis of a generally cylindrical air frame, such as a missile. In this case an antenna of sufficient length can be accommodated along the outer surface of the missile parallel to its longitudinal axis. Such straight waveguide antennas are not suitable, however, where it is desired to have the fan shaped radiation pattern of the antenna contained in a plane containing, or parallel to, the longitudinal axis of a cylindrical air frame. In such a situation there is not enough space in the transverse direction of the missile to accommodate a straight waveguide antenna with the necessary physical length to achieve sufficient directivity, without protruding and thereby affecting the missile's aerodynamic characteristics.

A first object of this invention is to provide a novel microwave antenna with non uniform spacing between radiating slots.

A further object of this invention is to provide a slotted wave guide antenna which can be supported by a curved airframe without affecting its aerodynamic characteristics, where the antenna radiation pattern is in a plane which contains or is parallel to the axis of curvature.

A still further object of this invention is to provide a slotted waveguide antenna which has a sharply defined null in a generally planar radiation pattern.

An additional object of this invention is to provide a slotted waveguide antenna which can alternate between a full planar radiation pattern and a planar radiation pattern having a sharply defined null therein.

These and other objects of the invention are achieved

by providing a curved slotted waveguide antenna, with the radiating slots in the broad face of the wave guide on the side away from the center of curvature.

The specific nature of the invention, as well as other objects, uses and advantages thereof, will clearly appear from the following description and from the accompanying drawing, in which:

FIG. 1 illustrates an antenna in accordance with this invention in combination with a generally cylindrical air frame;

FIGS. 2*a*, 2*b*, 2*c*, are views of the air frame antenna, and radiation pattern of FIG. 1 in the XZ, YZ, and XY planes, respectively.

FIG. 3 is a detailed view of the antenna of FIG. 1.

FIG. 4 is a modification of FIG. 3 wherein one arm of the antenna is fed out of phase with respect to the other arm.

The main lobe of a fan shaped radiation pattern of a straight slotted waveguide antenna, with staggered slots in the broad face of the antenna guide, is, as is known in the art, at an angle θ with respect to the longitudinal axis of the guide determined by

$$\cos\theta=\frac{\lambda}{\lambda_g}+\frac{n\lambda}{2D} \tag{1}$$

where λ is the free space wavelength, λ_g is the guide wavelength, D is the spacing between slots and n is an integer.

To design an array on a curved surface, such as the arc of a circle, analysis becomes more difficult, since the spacing between slots is not constant.

The equations for the spacing of the radiating slots along an arc of a circle are

$$\sin\ (\theta+\phi_k)-\frac{k\lambda}{\lambda_g}=\sin\theta+\frac{kn\lambda}{2R} \tag{2}$$

for staggered slots, that is, where the slots are on alternate sides of the longitudinal center line of the broad face of the guide, and

$$\sin\ (\theta+\phi_k)-\frac{\phi_k\lambda}{\lambda_g}=\sin\theta+\frac{kn\lambda}{R} \tag{3}$$

where the slots are all on one side of the longitudinal center line. As in (1), θ is the angle of the plane containing the radiation with respect a plane tangent to the circumference of the guide, λ is the free space wave length, and λ_g is the guide wavelength, but n is an odd integer. R is the radius of curvature of the waveguide and ϕ_k is the angle from the feed point to the kth slot.

Referring to FIG. 1, there is shown a missile **11** with a curved waveguide antenna **13** having a generally fan shaped radiation pattern **12** in an XZ plane, that is, a plane containing the longitudinal axis of the missile **11**. As can be seen in FIG. 1, by curving the antenna **13** a long antenna can be obtained that conforms to the short transverse dimension of the missile.

FIG. 3 is a detailed view of the antenna **13** shown in FIG. 1. The antenna **13** comprises a curved section of waveguide **15** having a radius of curvature R, a center of curvature at **14**, and a longitudinal center line **10**. The waveguide **15** has radiating slots **16** spaced at non-uniform predetermined distances in its broad face on the side away from the center of curvature **14**. The curved waveguide **15**, as shown, is center fed by a waveguide **17**, through a T connection **18**. The angle O, that is, the distance from the feed point **18** to each radiating slot **16**, is determined from Equation 2 or 3 above depending upon whether the slots are spaced on both sides or only one side of the longitudinal axis **10**. The angle θ is the angle between the plane of the fan shaped radiation pattern represented by **12** and a plane, represented by **19**, tangent to the curved waveguide section **15**. As in the

case of the straight slotted waveguide antenna of the prior art, the angle θ may be varied between wide limits, to suit a particular application.

Referring to FIG. 2, the radiation pattern for the antenna **13** is shown for the conditions when θ is equal to 90° and both halves of the waveguide **15** are fed in phase so that the radiation from each slot reinforces along the center line. FIG. 2*a* shows the radiation pattern of antenna **13** in the XZ plane of FIG. 1. FIG. 2*b* shows the radiation pattern of antenna **13** in the YZ plane, and FIG. 2*c* shows the radiation pattern of the antenna **13** in the XY plane.

Referring to FIG. 4, the radiation pattern of the antenna **13** is shown in the YZ plane (like FIG. 2*b*) when the radiating slots on one side of the feed point are fed 180° out of phase with respect to the corresponding slots on the other side. In this case a sharp null is produced on the beam axis as shown by the radiation pattern **21**. This sharp null can be produced either by shifting each radiating slot on one side of the T connection **18**, 180 electrical degrees relative to the corresponding slot in the other arm or by incorporating a phase shifter, such as ferrite phase shifter **24**, in one arm of the antenna **13**. Phase shifter **24** may comprise a small section of ferrite surrounded by a controllable magnetic field. As is well known in the art, the amount of phase shift introduced by the phase shifter **24** is dependent upon the strength of the magnetic field. A suitable control signal may be derived from radio pulse transmitter **26**, causing phase shifter **24** to introduce 0° or 180° phase shift in one arm of the antenna **13** on alternate pulse transmissions. A scheme of this type can be used to achieve a still greater narrowing of the effectiveness of the radiation pattern in the YZ plane of FIG. 1, by delaying only the echo signals received from the full pattern, for example, by an interval equal to the pulse repetition rate, and subtracting undelayed echo signals from the pattern with the sharp null therefrom, whereby echo signals will substantially cancel, except echo signals from the narrow null region.

While this invention has been more particularly described in connection with a center fed waveguide, it will be apparent to those skilled in the art that the antenna may be fed if desired, from the end, and still obtain the pattern shown in FIG. 2.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made through construction and arrangement within the scope of this invention as defined by the appended claims.

We claim as our invention:

1. A slotted waveguide antenna comprising: a curved section of waveguide, said curved section of waveguide having four walls, a longitudinal center line, and a center of curvature; a plurality of radiating slots spaced longitudinally along one wall of said curved section of waveguide, said one wall being the wall facing away from the center of curvature; means to couple microwave energy to be radiated into said curved section of waveguide; the spacing between said slots varying, the variation in spacing being a function of the distance from said coupling means, whereby said antenna radiates said energy substantially in a single plane, said plane being orthogonal to a plane which is determined by said longitudinal axis and said center of curvature.

2. A slotted waveguide antenna as in claim 1 wherein said curved section of waveguide is an arc of a circle.

3. A slotted waveguide antenna as in claim 1 wherein said radiating slots are disposed on both sides of said longitudinal center line.

4. A slotted waveguide antenna as in claim 1 wherein said radiating slots are disposed wholly on one side of said longitudinal center line.

5. A slotted waveguide antenna as in claim 3 wherein said plurality of radiating slots are spaced longitudinally along said one wall of said curved section of waveguide a distance from said coupling means determined by the equation

$$\sin(\theta+\phi_k)-\frac{\phi_k\lambda}{\lambda_g}=\sin\theta+\frac{kn\lambda}{2R}$$

where;

θ is the angle between the plane of radiation and a plane tangent to the curved section of waveguide; λ is the wavelength of the electromagnetic wave in free space; λ_g is the wavelength of the electromagnetic wave in the waveguide; ϕ_k is the angle measured at the center of curvature from the microwave energy coupling means to the k slot;

R is the radis of arc, and

n is an odd integer.

6. A slotted waveguide antenna as in claim 4 wherein said plurality of radiating slots are spaced longitudinally along said one wall of said curved section of waveguide a distance from said coupling means determined by the equation:

$$\sin(\theta+\phi_k)-\frac{\phi_k\lambda}{\lambda_g}=\sin\theta+\frac{kn\lambda}{R}$$

where;

θ is the angle between the plane of radiation and a plane tangent to the curved section of waveguide; λ is the wavelength of the electromagnetic wave in free space; λ_g is the wavelength of the electromagnetic wave in the waveguide; ϕ_k is the angle measured at the center of curvature from the microwave energy coupling means to the k slot;

R is the radius of curvature; and

n is an odd integer.

7. A slotted waveguide antenna as in claim 2 wherein: said means to couple microwave energy is located a distance from an end of said arc; said radiating slots are disposed on both sides of said coupling means; and means are provided to energize said radiating slots on one side of said coupling means in phase opposition to corresponding slots on the other side of said coupling means.

8. A slotted waveguide antenna as in claim 7, wherein said means to energize said radiating slots on one side of said coupling in phase opposition to the corresponding slots on the other side of coupling means comprises a ferrite phase shifter.

9. A slotted waveguide antenna as in claim 8, wherein said ferrite phase shifter is within said curved waveguide section adjacent to said coupling means.

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