July 12, 1966 P. L. MAST 3,261,018

MINIATURE HORN ANTENNA

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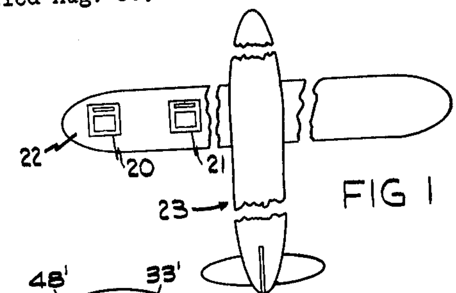

FIG 1

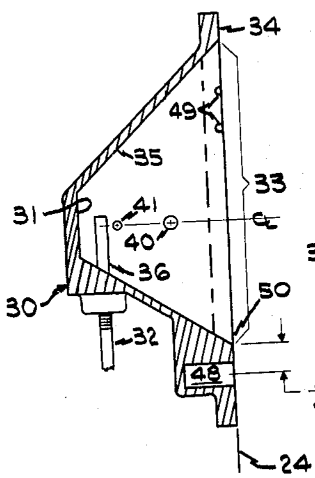

FIG 4

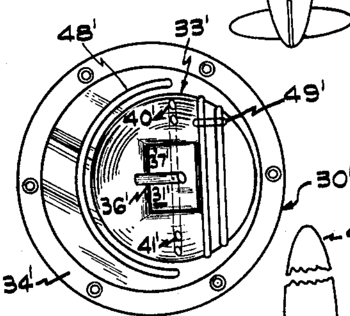

FIG 7

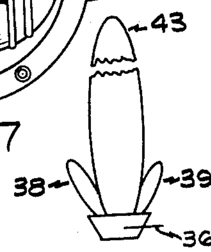

FIG 5

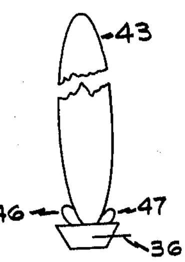

FIG 6

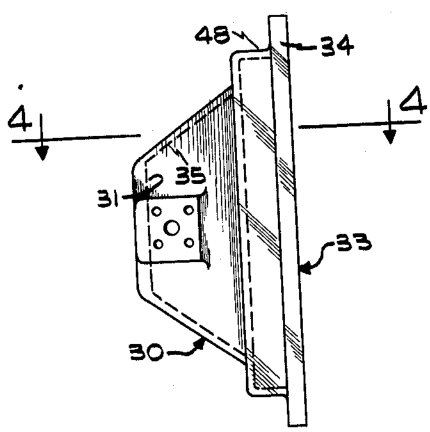

FIG 3

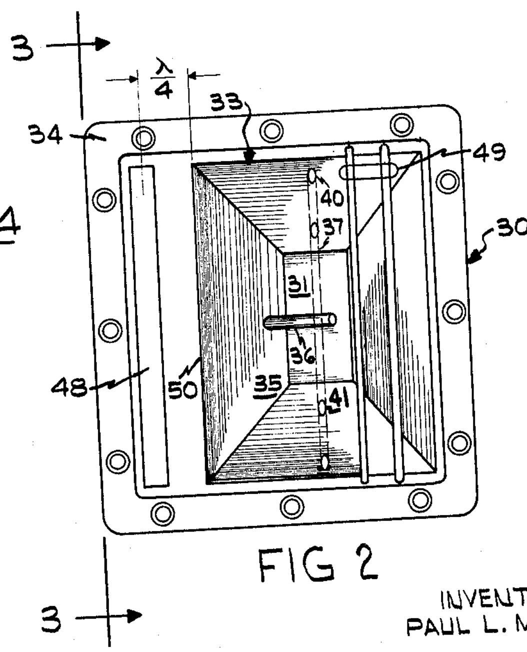

FIG 2

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MINIATURE HORN ANTENNA

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This invention relates to horn antennas and more particularly to miniature horn antennas, especially—although not exclusively—antennas for use with radar equipment.

A "horn antenna" is an antenna having a tube with a cross sectional area which flares or increases progressively toward an open end. The tube is energized with electromagnetic energy which first passes through the horn and then is radiated outwardly into space. Similar horn antennas are used to receive such radiated energy after which associated receiver equipment converts the energy into a useful form.

Bascially the horn type antenna functions as an impedance matching device interposed between a transmission line and space. At the extremely high frequencies used in radar and similar devices, electromagnetic energy must be transmitted through a transmission line (such as a wave guide) having a uniform impedance. The output load of the line is space which presents an impedance that does not match the impedance of the line. Without an impedance matching device, a portion of the energy in the line is reflected back onto the line at the line-load junction. However, with a proper impedance matching device (such as a horn antenna) the reflected signals are either cancelled or minimized to the point of negligibility.

To provide the impedance matching, one end of the horn antenna is generally made to match the line impedance and the other end of the horn is made to match the load impedance. A tapered or flared section (the horn) is interposed between these two ends to gradually change the line impedance to the space impedance. There is, of course, a slight mismatch at every point along the tapered section; however, any reflected signals are negligible.

The radiation pattern performance achieved from a horn antenna of the described is dependent upon many things but particularly upon the size of the aperture and the modes of illumination in the aperture (at load impedance of free space). The modes are to some extent determined by the degree of taper. In the past, the undesired modes have been prevented by using long taper sections to accomplish the impedance match between the aperture and transmission line. Rapid taper sections cause modes to be generated that give a radiation pattern that is generally considered undesirable.

Generally the problems of designing a horn antenna is merely one of adjusting the radiator dimensions to obtain the necessary impedance matches and desired radiation pattern performance. However, recent developments in other areas have changed the environment so that conventional techniques for matching impedance can not be used. For example, one use of horn antennas is in conjunction with airborne altimeters which include a pair of antennas mounted on an aircraft—generally in the wings of an airplane. A first of these horn antennas transmits radar signals downwardly toward the surface of the earth, and the second of these horn antennas receives reflections of such signals from the surface of the earth. Thus, by measuring the time required for the signals to be transmitted from the airplane to the ground and back again, computer-type equipment ascertains the altitude of the aircraft.

Recent developments in aircraft design demand thinner wings with a result that the horn antennas used heretofore in radar altimeters can not now be used. More

specifically, older horn type antennas generally had a minimum height of approximately six inches for C-band operation. However, some modern aircraft wings can only accommodate a horn antenna having a maximum height of two and one-half inches. Merely reducing the size of a horn to fit into these thin wings is, of course, not possible since very rigid performance standards must be met. Among other things, there must be at least 90 db isolation between the receiving and transmitting antennas. Moreover, the antenna pattern must have a main beam which is a single lobe of generally conical shape with a half-power beam width of approximately 35°. In addition, the antenna should suppress all except a desired one (the E10) of the many modes of propagation. It should especially suppress the H21 and E11 modes of propagation.

Accordingly, an object of this invention is to provide new and improved horn antennas and particularly horn antennas for airborne radar altimeters. A more particular object of the invention is to provide horn antennas of extremely small size. In this connection an object is to provide horn antennas having a maximum exterior height which does not exceed two and one-half inches.

Another object of the invention is to provide horn antennas of such non-critical dimensions that they may be manufactured through a use of low cost production techniques.

Yet another object of the invention is to increase the isolation between adjacent antennas. In particular, an object is to provide antenna patterns consisting of a single main beam with virtually no side lobes. Here an object is to provide a conical antenna pattern having a beam width in the order of 35° with about a 90 db isolation.

In accordance with one aspect of the invention, these and other objects are accomplished by means of a new and novel miniature horn antenna. Extremely high frequency energy is probe fed into a side of the flared horn. To prevent propagation of unwanted modes, ground potential suppressor rods are positioned in the horn at points where the unwanted higher order modes begin to generate. Side lobes of the antenna pattern are virtually eliminated by the use of either a slot or aperture rods for tapering the aperture illumination. The slot is positioned adjacent the horn aperture for reflecting out of phase energy back into the antenna pattern. It is thought that the aperture rods short circuit to ground the strongest modes in the side lobes. The energy content of any higher order modes remaining in the side lobes is negligible.

The flared horn has a somewhat "truncated pyramidal" shape. The term "pyramidal" is used loosely to describe any conelike or triangular object having a formation suggestive of a pyramid. The term "truncated" is used to describe the object as being terminated before it reaches an apex. Thus, a horn in the shape of a truncated pyramid will not be a delta-like end attached to a wave guide extending outwardly behind the horn. Instead, the horn will dead-end at the plane of the truncation.

The above mentioned and other features of this invention and the manner of obtaining them will become more apparent, and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a stylized showing of the lower side of an airplane showing transmit and receive antennas of a radar altimeter;

FIG. 2 is a plan view showing the front or aperture end of an exemplary horn antenna incorporating the principles of the invention;

FIG. 3 is a side elevation of the antenna taken along the line 3—3 of FIG. 2;

FIG. 4 is a cross sectional view of the side of the horn taken along the line 4—4 of FIG. 3;

FIG. 5 shows the antenna pattern of the antenna as such pattern would appear before the horn is modified as taught by this invention;

FIG. 6 shows the antenna pattern as it appears after the horn is modified as taught herein; and

FIG. 7 shows an alternative embodiment where the antenna horn tapers from a rectangular to a circular cross section.

Although horn antennas constructed according to this invention may be used in conjunction with any suitable electronic gear, two (20, 21) are shown in FIG. 1 as mounted in a wing 22 of an airplane 23. This airplane may take any convenient form—a stylized showing being here given merely for conveniences of explanation. In like manner, the wing mounting is shown solely because the thin configuration of high speed wings were the primary motivation for miniaturization of the antenna—the antennas may be mounted in other locations also. To function as radar altimeters, the antennas must, of course, point downward toward the earth and be placed so that no obstructions are located between the antennas and the earth. Moreover, the antennas should be located at a place on the airplane far enough from radar wave reflecting parts (such as motors, fins, pods, and the like) so that such parts will not affect the antenna performance.

Typical dimensions, which are believed to be particularly important in this invention, may be given as follows. The spacing between the back of the antenna 30 and the ground plane 24 typically will be about 2½ inches. The spacing between the inner portions of the back of the antenna 31 and the coaxial line input 32 will be 0.4 inch. Spacing between the inner back surface of the antenna 31 and the suppressor rod 41 will be .622 inch. Spacing between the ground plane 24 and the suppressor rod 41 will be .778 inch. The distance across the back of the antenna horn as shown in FIG. 3 would be about 2 inches. The aperture rods 49 as shown in FIG. 2 would be about .562 inch and 1.125 inches, respectively, from one of the inner edges of the aperture 33. In a typical case, the spacing between the center lines of the antennas as illustrated in FIG. 1 will be about 3 feet.

Preferably, the antennas 20, 21 are positioned with their E planes parallel and the long axes of their apertures in alignment. The antennas are separated by approximately three feet measured between the center points of the apertures in the ground plane (i.e. in plane 24—FIG. 4). As here shown, either of the antennas 20, 21 may function as a transmitting device, and the other functions as a receiving device.

The general configuration of an exemplary antenna will be apparent by inspection of FIGS. 2–4. Primarily, the antenna comprises a unitary structure 30 preferably made of cast aluminum. The upper end 31 of the horn dead-ends and serves as part of the matching to the impedance of the coaxial line input 32. The aperture or lower end 33 of the horn carries a continuous flange 34 for flush mounting the antenna and has dimensions which generally match the impedance of the horn to the impedance of space. Between these two ends 31, 33, the horn comprises a flared skirt portion 35 which tapers to gradually change impedances, thereby matching the line 32 impedance to the impedance of space. The flare or taper occurs along each of two axes located at right angles to each other, thus giving the horn a generally rectangular cross section.

Extremely high frequency energy is probe fed at 36 through the long side of the flared horn near the small end 31 thereof. From an inspection of the drawing, it should be apparent that probe 36 projects through the center of the long side of the flared skirt 35 near the small end 31 and extends into the horn parallel to the small side 37 of the rectangular cross section. Heretofore, the horn did not dead-end at the small end 31, as shown, but terminated here in an opening joined to a section of a wave guide. Sometimes this wave guide section also included a septum to polarize the electrical field in the horn, the wave guide section and septum adding several inches to the outside height of the horn. With the side entrance probe feed and the rapid taper necessary for minimum size shown here, the antenna pattern has two large and unequal side lobes 38, 39 (FIG. 5) and is much more likely to generate unwanted electromagnetic fields having a higher order mode structure. The probe feed is shown in FIGS. 5 and 6 to orient the pattern with respect thereto.

To suppress these unwanted higher order modes, one or more parallel suppressor rods 40, 41 are placed inside the tapered portion of the horn perpendicular to the probe feed. As shown in phantom by dot-dashed lines (FIG. 2), these rods extend through the horn and are positioned between the probe 36 and aperture 33; they are oriented perpendicular to the probe. The physical dimensions of these rods are not too critical. Therefore, an antenna designer is guided primarily by such practical considerations as availability of raw stock rods, mechanical support required for the length of the rod used, etc. However, after giving due consideration to these practical aspects, the designer will normally select rods having the smallest practical diameter.

The locations of the suppressor rods 40, 41 depend upon the cross sectional dimensions and configurations of incremental sections of the horn considered as a wave guide. That is, due to the cross sectional size of the horn, electromagnetic fields of unwanted higher order modes begin to propagate at specific points. The suppressor rods are placed at these points to provide ground potentials. This way the unwanted modes are shorted to ground. Known mathematical techniques are used to ascertain the exact spots where grounded suppressor rods should be located. Nevertheless, to illustrate where the rods were placed in one exemplary construction, I have placed certain dimensions on the drawing. However, the invention should not be construed as limited to these particular dimensions—or to any other specific configuration.

Actually, the principal purpose of the suppressor rods 40, 41 is to give proper polarization to the signal of the main antenna beam 43. Before addition of the suppressor rods 40, 41 the unwanted modes were estimated to be less than 1% of the signal strength of the main beam 43. This small percentage of the total signal does not cause trouble in and of itself; it is the unpolarized nature of the main beam including the unwanted signal that causes the trouble. After addition of the rods 40, 41 in the exemplary antenna, these unwanted modes could not be detected. Thus, the beam pattern is completely polarized in the direction to achieve maximum isolation for all practical purposes.

The side lobes 38, 39 of the antenna pattern may be reduced to negligible values (as shown at 46, 47) through the use of either or both a slot 48 adjacent the horn aperture 33 or aperture rods 49. Both the slot 48 and the rods 49 are oriented parallel to the suppressor rods 40, 41 and perpendicular to the probe 36. The drawing shows—and the noted exemplary construction actually used—both the slot and the aperture rods. However, the selection and use either of a slot or rod will vary from one design to another—sometimes one is used, sometimes the other, sometimes both.

The term "aperture illumination" is used to describe how the intensity of the voltage field varies over the surface 24 of the aperture 33 in the large end of the horn. This surface is sometimes called the "ground plane." By reference to FIG. 5, it will be apparent that the two unwanted side lobes may be described as a divergence or spreading of the antenna beam. In like manner, an elimination of the side lobes (as shown in FIG. 6), may be described as tapering the aperture illumination in the desired manner. The spreading is unwanted because it tends to couple the transmit and receive antennas should an object be in the path of the side lobes, thereby reducing the isolation between them. Therefore the tapering is wanted to increase the isolation and make a generally better design.

To taper the aperture illumination, one or more aperture rods **49** are placed within the aperture of the horn and in the ground plane **24**. It is though that the net effect of the aperture rods is to serve as a parasitic radiator within the aperture itself. The excitation of this radiator is controlled by the size and position of the rods. The number of rods placed in the aperture depends upon their size, location and spacing, factors which are best determined experimentally. Experimental results indicated at **46, 47** in FIG. 6 were obtained. In the exemplary construction, these rods weer placed at the locations noted in the drawing.

The slot **48** on the side of the aperture **33** reflects out of phase energy which mixes with and cancels some of the energy to taper the aperture illumination as shown in FIG. 6. The exact width and location of the slot is determined by the amount of out of phase energy needed. Preferably, this slot is placed parallel to the long edge **50** of the aperture **33** and spaced from the aperture so that the distance between the nearest edge of the aperture and the center of the slot is about one-quarter wave length of the nominal frequency of the main antenna beam. Also preferably the slot **48** has a rectangular cross section and is a quarter wave length deep. The width of the slot is found by experimentation. These quarter wave length and other dimensions are approximations which serve as a starting point from which experimentation is used to ascertain the exact dimensions for the slot used with any given antenna design.

The signal strength of the side lobes **38, 39** of the described antenna is about 13 db down from the signal strength of the main beam **43** before the aperture rods or the slot are added. One side lobe **38** is much more pronounced than the other **39** owing to the positioning of the side entrance probe **36**. The slot reduces this side lobe to main beam signal strength ratio to about 15 db, and the aperture rods reduce the ratio to about 18 db. Thus, a near equality of side lobes may be achieved by using the slot to reduce the large lobe and the rods to reduce the inter-related part of the large and small lobe.

Other modifications will readily occur to those skilled in the art. For example, this design should not be construed to be limited to rectangular cross section antennas. It can be used with virtually any physical shape. For example, a partially circular antenna with a generally crescent shaped slot (as shown in FIG. 7) has been built and tested. This antenna was found to function about the same as the above described rectangular antenna of the preferred embodiment. Therefore, the same reference numerals are used to identify the same parts in FIGS. 2 and 7.

The advantages of the invention are many. The smaller configuration not only allows the antenna forms to fit into smaller spaces, but also reduces the weight that an airplane must carry. Moreover, the superior performance of this antenna increases the safety of air travel and reliability of other high frequency equipment. In addition, the dimensions of the horn are so non-critical that inexpensive sand casting techniques may be used to reduce the cost of manufacture. Still other advantages will readily occur to those skilled in the art.

While the principles of the invention have been described above in connection with specific apparatus and applications, it is to be understood that this description is made only by way of example and not as a limitation on the scope of the invention.

I claim:

1. A miniature extremely high frequency antenna comprising a truncated pyramidal horn having a closed end of relatively small cross section and an open end of relatively large cross section with a flared skirt therebetween, means for feeding energy into the side of said flared skirt near the closed end thereof, means in said horn for suppressing the generation of electromagnetic fields having unwanted higher order mode structure, and means near the open end for tapering the aperture illumination of said horn to reduce the side lobes of the antenna pattern to negligible values.

2. The antenna of claim **1** wherein said horn has an elongated rectangular cross section in at least a portion of said flared skirt, said energy feeding means comprising a probe projecting through said flared skirt on the long side of said rectangular cross section and extending into said horn parallel to the short side of said rectangular cross section, said suppressing means comprises at least one rod at ground potential extending through said horn, said rod being positioned between said probe and the open end of said horn and oriented perpendicular to said probe.

3. The antenna of claim **1** wherein said open end has a rectangular cross section, said aperture illumination tapering means comprising a slot positioned parallel to and approximately a quarter wave length from an edge of said cross section and in the plane of said open end.

4. The antenna of claim **3** wherein said slot is approximately one quarter wave length deep.

5. The antenna of claim **1** wherein said aperture illumination tapering means comprising at least one rod extending across said open end in the plane thereof.

6. The antenna of claim **1** wherein said open end has a circular cross section, said aperture illumination tapering means comprising a somewhat crescent shaped slot partially surrounding said circular end.

7. A miniature antenna for operating in the radar frequency spectrum comprising a horn having a closed end of relatively small cross section and an open end of relatively large cross section with an elongated rectangular cross section flared skirt therebetween, means comprising a probe extending parallel to the short side of said cross section for feeding energy through the long side of said flared skirt near the closed end thereof, means in said horn for suppressing electromagnetic fields having unwanted higher order mode structures comprising at least one rod at ground potential extending through said skirt between said probe and the open end of said horn oriented perpendicular to said probe and positioned at a point where an electromagnetic field of said unwanted higher order modes begin to propagate, and means comprising at least one rod extending across said open end in the plane thereof for tapering the aperture illumination of said antenna to reduce the side lobes of the antenna pattern to negligible values.

8. The antenna of claim **7** and a slot adjacent said open end positioned parallel to and approximately a quarter wave length from an edge of said open end for reflecting out of phase energy back into said antenna pattern.

9. A miniature antenna for operating in the radar frequency spectrum comprising a horn having a closed end of relatively small cross section and an open end of relatively large cross section with a flared skirt therebetween, means comprising a probe extending into and partially across said skirt perpendicular to the major axis of said flare for feeding energy through the long side of said flared skirt near the closed end thereof, means in said horn for suppressing electromagnetic fields having unwanted higher order mode structures comprising at least one rod at ground potential extending through said skirt between said probe and the open end of said horn oriented perpendicular to said probe and positioned at a point where an electromagnetic field of said unwanted higher order modes begin to propagate, and means comprising at least one rod extending across said open end in the plane thereof for tapering the aperture illumination of said antenna to reduce the side loebs of the antenna pattern to negligible values.

10. The antenna of claim **9** and a slot adjacent said open end positioned parallel to and approximately a quarter wave length from an edge of said open end for reflecting out of phase energy back into said antenna pattern.

11. A horn antenna for use in an extremely high frequency spectrum comprising a partial enclosure extending in a flared truncated pyramidal configuration from a relatively small closed end to a relative large aperture, means for broadcasting energy from said aperture at said high frequency, said broadcast energy having a characteristic antenna pattern, and means comprising at least one ground potential rod extended across said aperture for tapering said pattern.

12. A horn antenna for use in an extremely high frequency spectrum comprising a partial enclosure extending in a flared configuration from a relatively small closed end to a relatively large aperture means for feeding energy into the side of said flared configuration near the closed end thereof, means for broadcasting energy from said aperture at said high frequency, said broadcast energy having a characteristic antenna pattern, means near the aperture for tapering the aperture illumination of said horn to reduce the side lobes of the antenna pattern, said tapering means comprising at least one rod crossing said open end in the plane thereof, and means comprising at least one slot positioned in the ground plane of said antenna adjacent to said aperture for tapering said pattern, said slot being approximately one-quarter wave length from said aperture and one-quarter wave length deep.

13. A pair of miniature truncated pyramidal horn antennas for mounting in the wing of an aircraft having a high speed air foil, the horns in the wing pointing downward toward the surface of the earth when said aircraft

is in flight, said antennas being positioned on said wing with their E planes parallel, each of said antennas comprising a truncated pyramidal horn having a closed end of relatively small cross section and an open end of relatively large cross section with a flared skirt therebetween, means including a probe projecting through said flared skirt and extending across at least a part of the interior of said horn for feeding energy through the side of said flared skirt near the closed end theerof, and means near the open end for tapering the aperture illumination of said horn to reduce the side lobes of the antenna pattern to negligible values, said means for tapering comprising at least one rod crossing said open end in the plane thereof perpendicular to said probe, said means for tapering thereby increasing the isolation between said antennas.

14. The horn antennas of claim 13 and a slot positioned parallel to and approximately a quarter wave length from an edge of said open end to reflect out of phase energy back into said antenna pattern.

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