Oct. 13, 1942.

W. L. BARROW

2,298,272

ELECTROMAGNETIC HORN

Filed Sept. 19, 1938

4 Sheets-Sheet 1

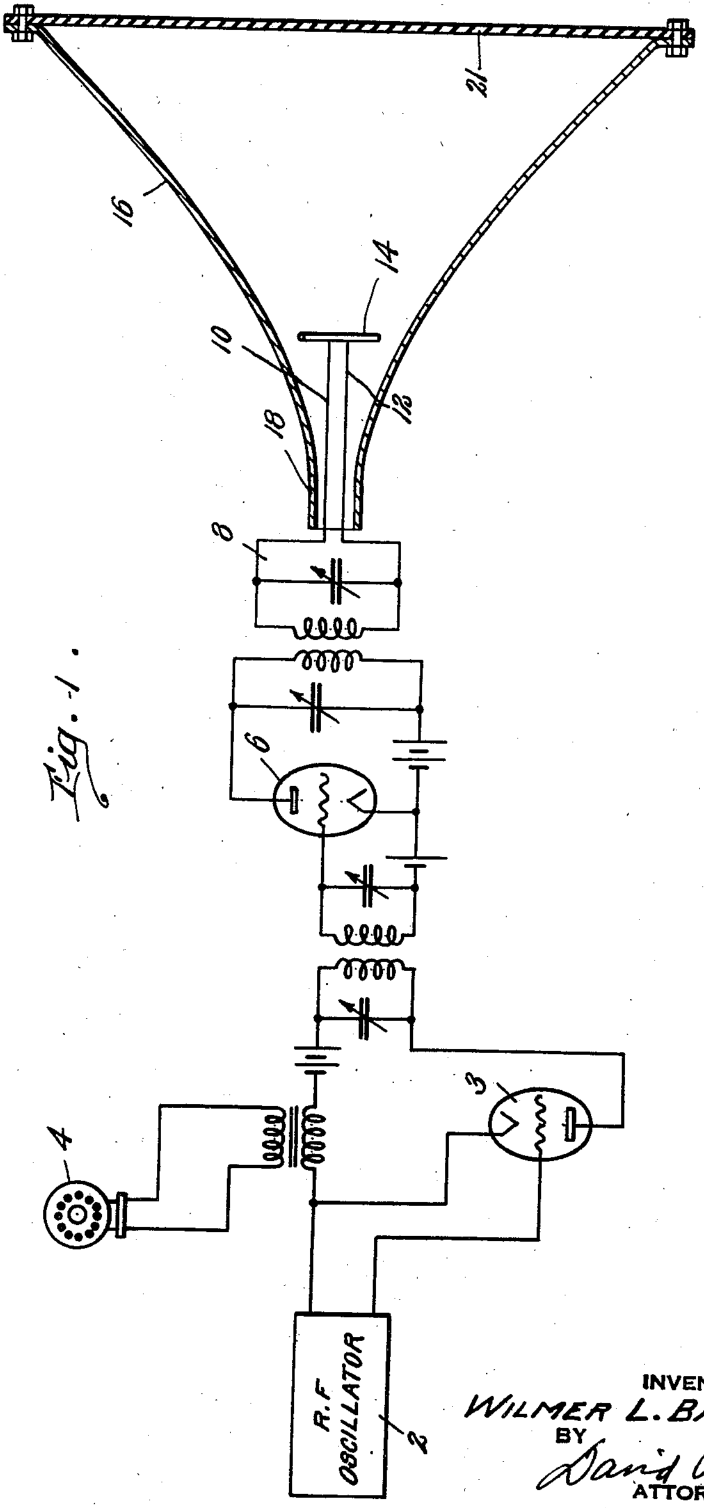

Fig. 1.

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Fig. 2.

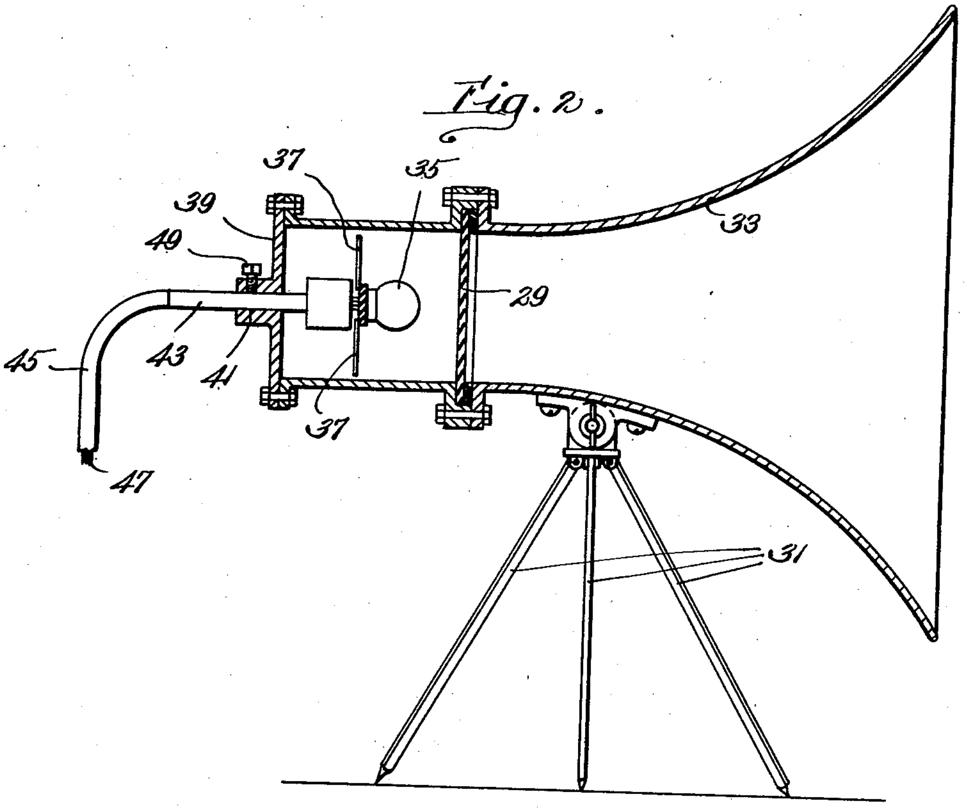

Fig. 3.

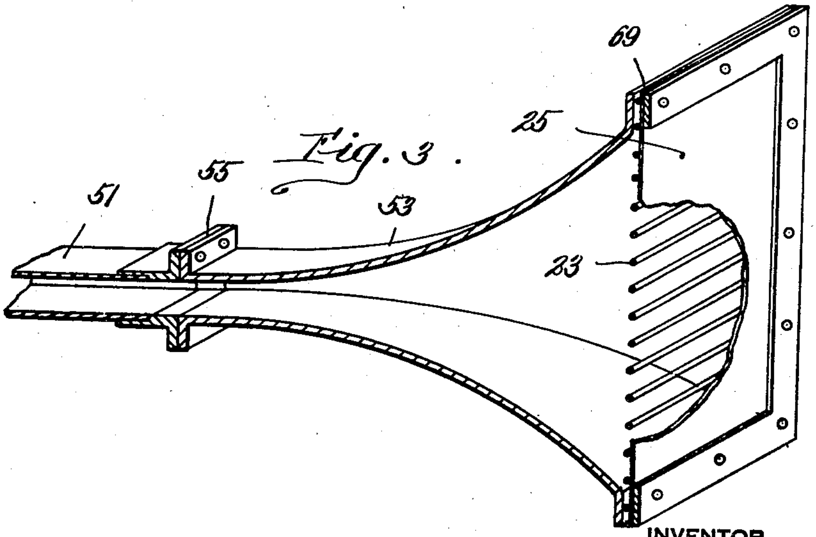

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Fig. 4.

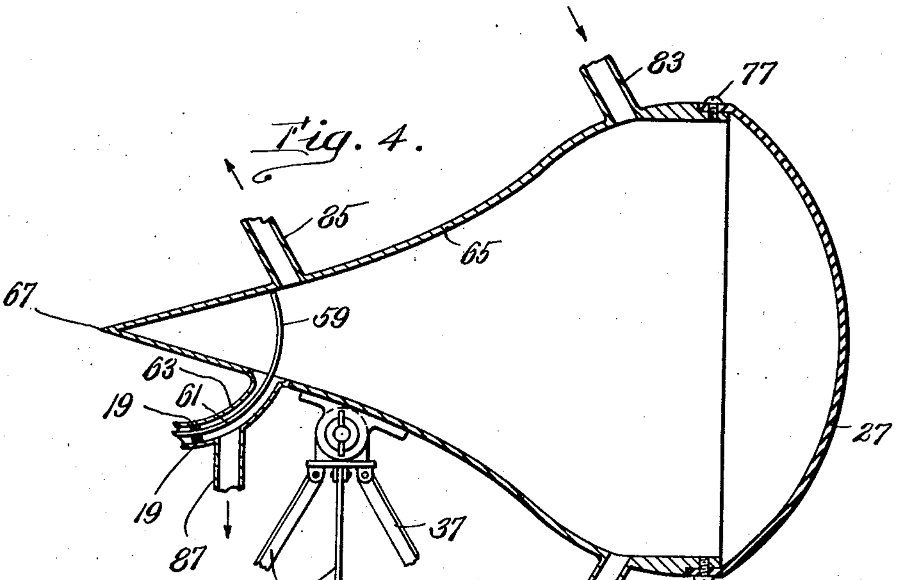

Fig. 5.

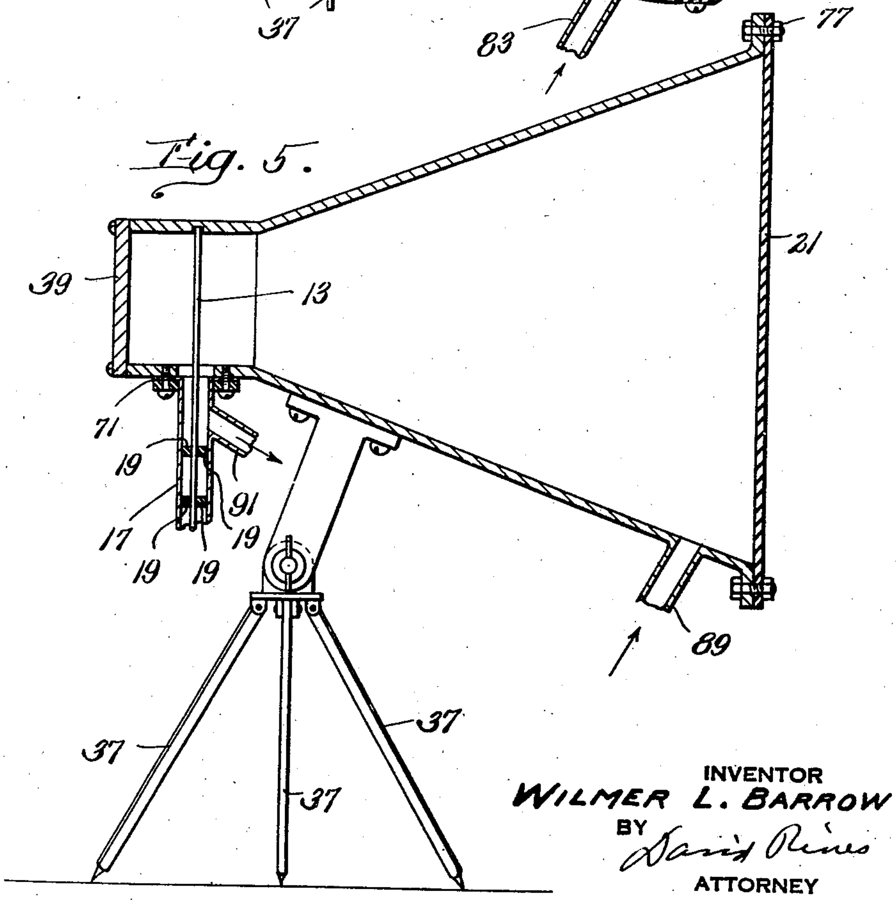

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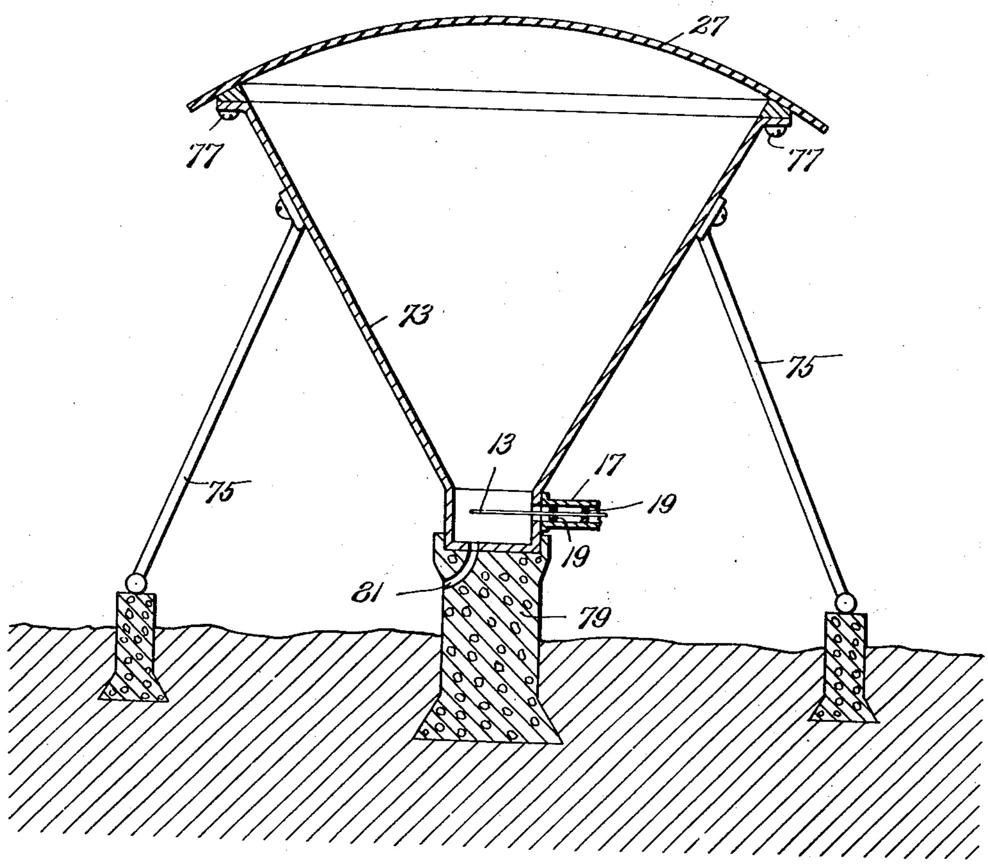
Fig. 6.



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2,298,272

ELECTROMAGNETIC HORN

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Application September 19, 1938, Serial No. 230,737

6 Claims. (Cl. 250—11)

The present invention relates to electromagnetic radiators and absorbers, such as hollow wave-guide pipes and horns.

Since electromagnetic horns and pipes must often be located out of doors, they will be subject to all weather conditions. As rain, sleet and snow may, therefore, enter the mouth of the horn or pipe, its efficiency will become impaired, either by coating of the sides of the horn or pipe with ice and sleet, or by damaging or otherwise deteriorating the interior surface of the horn or pipe, the antenna at the throat of the horn, and the associated transmission line, vacuum tube or other apparatus that may be connected to, or inserted in, the horn or pipe. Insects, small animals and the like, furthermore, if they should happen to enter the horn or pipe, might impair the operation of the apparatus contained therein, or even damage the structure.

An object of the present invention, therefore, is to provide novel protection for electromagnetic pipes and horns of the above-described character, as well as the mechanisms contained therein, against storms, the activities of live objects, and the like, but without impairing the efficiency of transmission or reception of the pipes and horns.

To this end, the pipe or horn is provided with a dielectric barrier. This barrier protects the inside of the horn from the elements, but without appreciably affecting its electrical characteristics.

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

The invention will now be described in connection with the accompanying drawings, in which Fig. 1 is a longitudinal diagrammatic section of an electromagnetic horn embodying the present invention, shown connected to circuits suitable for transmission; Fig. 2 is a similar section of a modified arrangement; Fig. 3 is a perspective of another modification, partly in longitudinal section and partly broken away; and Figs. 4 to 6 are further longitudinal sections of further modifications.

In Fig. 1, there is shown a system comprising a radio-frequency oscillator **2**, connected with a modulator **3**, which may be modulated in any desired way, as by means of a microphone **4**. The modulated output may be fed to a radio-frequency amplifier **6** that may be coupled to a circuit **8** having balanced parallel-line output leads **10** and **12**. Sending or receiving apparatus may be connected to the two-wire line leads **10** and **12**. The leads **10** and **12** are shown connected to an exciting or absorbing antenna rod **14**, disposed approximately centrally, in or near the small end or throat, and substantially at right angles to the axis, of a horn **16**. Electromagnetic waves produced by the exciting rod **14**, in or near the small end of the horn, will be transmitted in the horn **16** and radiated out into space. The horn **16** thus constitutes a directive electromagnetic radiator.

A similar but reverse action will take place for absorption or reception of such waves, the electromagnetic waves being received by the horn and communicated to a receiving system. The electromagnetic energy received by the horn may be transmitted to a terminal device having a conducting tube and a conductor, disposed either axially or transversely of the pipe or the horn. The conductor and the conducting tube are respectively connected by conductors of a bi-conductor system to a circuit that may be coupled to a detector. The detector may be coupled to an amplifier that, in turn, may be connected to a loud speaker.

The horn **16** is illustrated as constituting a flared-out continuation, at the free open end, of an elongated tubular or pipe body portion or section **18** that may extend over any desired distance from the horn to the left, as viewed in Fig. 1, to the apparatus **8**, **6**. The pipe portion **18** may constitute a shield for the balanced two-wire line **10**, **12** which, as before stated, may lead to any desired suitable apparatus. The principal axis of the horn extends between the smaller and the larger ends of the horn.

The electromagnetic horn may be circular or round in cross section, or it may be of simple rectangular shape. For beam transmission, the rectangular cross section, with an orientation of the exciting rod perpendicular to the pipe axis, offers certain features, among them the important feature of a radiated space wave polarized with the electric vector mainly in a single direction. Other shapes also may be employed, either for receiving or sending, and either with the conventional bi-conductor lines or the hollow-pipe system illustrated and described in my article, entitled, "Transmission of electromagnetic waves in hollow tubes of metal," Proceedings of the Institute of Radio Engineers, October, 1936, page 1298.

There is a minimum or critical frequency for each type of wave below which it cannot exist in, and cannot be transmitted through, the hollow pipe. This critical frequency is different for each type of wave and for different pipe materials, shapes and cross-dimensions. As given on page 1323 of my said paper, for a pipe of circular cross section, the minimum frequency f_0 below which no transmission can take place by any type of wave is:

$$f_o=\frac{1.841}{2\pi a\sqrt{\mu_1\epsilon_1}}$$

where f_0 is the minimum frequency, for any transmission, in cycles per second,

a is the radius of the inside circular conducting wall of the pipe, in centimeters,

μ_1 is the permeability of the interior, which permeability, for air, most gases, or a vacuum, is $4\pi\times10^{-9}$,

ϵ_1 is the dielectric constant of the gas or the vacuum, the value of which is

$$\frac{10^{-11}}{36\pi}$$

and $\pi=3.1416$.

The value f_0, however, applies to a particular wave. Each type of wave has its own critical frequency.

For air-filled pipes, this formula becomes

$$\lambda=3.41a$$

where λ is the wave length corresponding to the frequency f_0.

The type of wave that is possible if the frequency equals or exceeds by a slight amount the value of f_0 given by this formula may be referred to as the first-order transverse wave. As the frequency is raised above this value, other types of waves are possible, each of which has its own critical frequency. The type of wave having the second-lowest critical frequency, for example, may be referred to as the zero-order longitudinal wave. It can exist only if the frequency equals or exceeds the frequency given by the same formula, except that the constant 1.841 is replaced by 2.405, a circular cross-sectional pipe being again referred to.

Other types of waves have successively higher values for their critical frequencies. Although there is a very large number of these wave types, the first several types are at the present time of the most practical application for reasonably small pipe diameters.

As a special case, the cross section may also be uniform, one end of the hollow pipe or horn being left open to connect it directly to outside space. The pipe is thus enabled to receive electromagnetic waves from space or to radiate electromagnetic waves out into space at the open end of the pipe. The straight uniform portions of the hollow tube may be long enough—say five wave-lengths long at the particular frequency of transmission—to provide waves of the hollow-pipe type; but with a transverse antenna, the pipe may be quite short.

The horn may be constituted of metal, such as copper or aluminum, or it may be constituted of other material if its inner wall is otherwise rendered a conductor of the said waves. The interior of the horn, being open to the atmosphere, is naturally a non-conductor. In some cases, indeed, the pipe that is flared into the horn may be constituted wholly of dielectric material. The hollow pipe body portion **18** to which the horn is connected may be of any desired material, conducting or dielectric.

Though the invention is illustrated in Fig. 1 in connection with the conventional parallel-line system, it may be employed also with coaxial-line systems, as illustrated in Figs. 4 to 6. One of the wires, as the wire **10**, may be connected to the outer tubular conductor **17** or **63** of the coaxial-cable feed-line. The other wire, as the wire **12**, may be extended into the bell of the horn, axially thereof and of the tubular body portion **18**, to form the center or inner conductor of the coaxial line, as illustrated at **13** and **59**. The exciting rod **14** of Fig. 1, or **13** and **59** of Figs. 4 to 6, may be disposed unsymmetrically in the horn, to give a modified directive pattern for the radiant energy.

In Fig. 4, the exciting rod **59**, which constitutes the projecting extension of the inner conductor **61** of the coaxial-cable line **61**, **63**, is given a suitably curved form, so as to coincide with an arc of a circle with its center at the vertex **67** of the horn. By so curving the exciting rod, the waves may be caused to have the same phase on arcuate surfaces at smaller distances from the exciting rod than obtains with straight exciting rods. Fig. 4 also illustrates a horn having the small terminal end continued without discontinuity to the vertex **67** to provide a flaring or stream-lined construction in profile to reduce wind resistance, which is a factor to be considered in some applications, as in airplanes. Although illustrated as conical, the closed tapered end of the horn may be curved in other shapes to a point. This tapered closed end partially obviates reflections from the closed end of the horn, to the left of the rod **59** in Fig. 4, thereby suppressing the resonance effects observed with metal reflecting end walls such as illustrated at **39** in Figs. 2 and 5. The suppression of resonance in this way provides a relatively broad response characteristic, allowing the horn and its associated appaartus to operate over a wide range of frequencies. It also makes the adjustment of the exciting rod with respect to the closed end of the horn less critical.

The conductors **13** and **59** are shown supported in and spaced from the walls of the tubes **17** and **63** by insulating spacer members **19**. The wires **10** and **12** of Fig. 1 may be similarly supported, but the supports are omitted, for clearness.

In accordance with a feature of the present invention, the metal horn is provided with an insulating barrier or closure. This barrier may be continuous, as shown at **21** and **27**, or it may be in the form of a horizontally disposed grid **23**, constituted of horizontally disposed metal or non-metal bars or rods, with or without the hereinafter-described covering or membrane **25**. Particularly if the horn is of rectangular cross section, the rods of the grid, constituted of metal, may be disposed substantially at right angles to the antenna **14** and thus also to the electric lines of force in the wave. If as illustrated in Fig. 3, the bars are horizontally disposed, waves of the $H_{0,1}$ type, with a vertical polarization of the electric field, will go through the horizontally disposed grid, their intensity unimpeded. Since the bars or rods are at right angles to the electric-field intensity, they have small effect electrically. The grid will not appreciably affect the operation of the horn. When types of waves other than the $H_{0,1}$, and cross-sectional shapes other than rectangular, are used, the bars of the grid may be given other appropriate shapes that allow the waves to pass through relatively unimpeded. In such cases, the bars may be made orthogonal to the lines of electric force in the wave on the cross-sectional surface where the grid is located. If the antenna **13** is vertical, for example, as in

Fig. 5, the grid bars should be horizontal, or at right angles to the antenna **13**.

The grid may serve also as a mechanical support for a thin sheet of non-conducting weatherproof and water-proof diaphragm covering **25**, say, of rubber cloth, silk, linen or other material, stretched across, or over, the mouth of the horn, to close or seal the horn, and thus keep out rain, snow, sleet, water, and so on, and even the wind. The horn radiator or absorber so constructed will be watertight and proof against the elements. The covering material may be pliable or semi-pliable, so as to be flexible, as illustrated at **25** in Fig. 3, or it may be solid and self-supporting, as shown at **21** in Fig. 5, and of dielectric coefficient and loss and conductivity as low as appropriate to pass freely the ultra-high-frequency waves involved, with little loss. Glass, sheets of victron, thin ply-wood, and treated wood or fabric, such as airplane silk or other cloth, canvas and textolite are examples of suitable materials.

If desired, a direct, a 60-cycle, or another low-frequency heating current may be sent through the rods of the grid **23**, to melt ice and sleet. The rods may, furthermore, be mechanically vibrated to and fro, through a small amplitude, to keep ice from forming on the protective covering **25**. Air, heated or otherwise, as hereinafter described in connection with Figs. 4 and 5, may be circulated through the interior of the horn in pulses, periodically to flex the covering, thereby to prevent the formation of ice.

The dielectric covering over the mouth may be flat, as shown in Figs. 1, 3 and 5, or it may be curved or otherwise bulging, as illustrated at **27** in Figs. 4 and 6, so as to coincide substantially with a wave-front of the wave emerging from the horn thereby to reduce reflections and losses within the horn, without affecting so much the radiation pattern. The dielectric barrier **27** may, therefore, be curved in the form of a sphere, with the center at the throat or apex **67**, or it may be curved to constitute the outer contour of the horn a "tear drop" or other stream-lined shape. The curved shape may be supported by suitably shaped grids, of the character described above, in connection with Fig. 3.

This weather-proof dielectric closure may be located across the mouth of the horn, or inside the horn, in the vicinity of the throat **33**, as illustrated at **29**, in Fig. 2. This disposition of the closing material has particular application to very large horns, where the cost and construction difficulties would otherwise be great. Not only the mouth, but also the back end of the horn, and the connections to the transmitting apparatus or power supplies, should be made water-proof, as illustrated in Figs. 2 and 4 to 6.

Vacuum tube or other energy-translating apparatus **35**, such as the Peterson oscillator described in the General Radio Experimenter for October, 1937, together with projecting exciting or absorbing antenna rods **37** connected thereto, may be mounted in the closed chamber formed between the metal or non-metal wall **39** at the throat or small end of the horn and the covering **29**. The wall **39** is provided with an opening **41** in which the tube **43** is rendered slidably adjustable. The tube **43** may be held in adjusted position by means of a binding screw **49**. Adjustment of the tube **43** will effect adjustment of the antennae **37** and the oscillator **35** with respect to the wall **39**, thus providing for tuning the apparatus. A shielded waterproof cable **45** is connected to the oscillator **35** through the tube **43** to carry power and modulation leads **47**.

The back wall **39** shown in Fig. 5 may be of the same nature as described above in connection with Fig. 2, tightly closing the throat of the horn. The outer conductor **17** of the coaxial cable **17**, **13** is tightly fitted to the throat of the horn by a water-proof flange joint **71**.

A hollow-pipe transmission line **51** is illustrated in Fig. 3 connecting the hollow pipe apparatus to the horn **53**. Though this horn **53** may be round in cross section, it is shown square, but flaring. The hollow pipe **51**, which may be flexible or curved, is shown connected to the small end of the horn **53** by a weather-proof joint **55**. The covering material **25** is connected to the mouth of the horn by a similar weather-proof joint **69**.

The horn of Figs. 2, 4 and 5 is shown pivotally adjustable on its support **31** or **37**. The horn **73** is illustrated in Fig. 6 as permanently held rigidly in vertical position by means of stays or other holding members **75** on a foundation **79**, for use as a marker, beacon and the like. It may, however, occupy any other position, horizontal or inclined. The dielectric covering **27** may be held in place by fastening members **77**, or by separate members, not shown. A protective drain **81**, disposed at any suitable point, such as in the lower or small end of the horn, shown extending through the foundation **79**, will prevent the accumulation of liquids in the horn, thus keeping the coaxial cable **13**, **17** and the antenna **13** free of liquid.

In order further to protect the horn against the elements, hot air may be forced thereinto to heat its side walls and, particularly, the dielectric covering, thereby to effect melting of ice and snow and to assure regular operation under ice, snow and other storm conditions. Two embodiments of this feature of the invention are illustrated in Figs. 4 and 5.

In Fig. 4, hot air is adapted to enter through a plurality of pipes **83** disposed near the mouth of the horn in directions such as to direct the hot air against the dielectric barrier **27**. After circulating in the horn, the hot air may leave by way of pipes **85** and **87** near the small end of the horn. The pipe **87** is shown communicating with the outer tubular conductor **63** of the coaxial line **61**, **63**. The direction of the hot air is indicated by the arrows. A similar arrangement is shown in Fig. 5, the hot air entering by way of a single tube **89** and leaving by a single tube **91**, in the direction of the arrows.

It will be understood that the invention is not limited to the exact embodiments thereof that are illustrated and described herein, but that further modifications may be made by persons skilled in the art without departing from the spirit and scope of the invention, as defined in the appended claims.

What is claimed is:

1. A device of the character described comprising a hollow wave-guide pipe open to space at one end to permit the pipe to receive electromagnetic waves from space or to radiate electromagnetic waves out into space at the said end, the dimensions of the pipe corresponding to a critical wave-frequency less than the frequency of the said received or radiated waves in order to permit transmission of the said waves through the pipe, and a curved dielectric closure disposed in the pipe, the curve of the closure coinciding

substantially with the wave-front of the said waves.

2. A device of the character described comprising a vertically disposed electromagnetic horn having a smaller end and a larger flared open end, means for transmitting electromagnetic waves in the horn, and a curved dielectric closure disposed in the horn, the curve of the closure coinciding substantially with the wave-front of the said waves.

3. A device of the character described comprising an electromagnetic horn having a smaller end and a larger flared open end, means for transmitting electromagnetic waves in the horn, and a curved dielectric closure disposed in the horn, the curve of the closure coinciding substantially with the wave-front of the said waves.

4. A device of the character described comprising an electromagnetic horn having a smaller end and a larger flared open end, means for transmitting electromagnetic waves in the horn, and a curved dielectric closure disposed in the horn adjacent to the larger end, the curve of the closure coinciding substantially with the wave-front of the said waves.

5. A device of the character described comprising a streamlined electromagnetic horn having a smaller end and a larger flared open end, means for transmitting electromagnetic waves in the horn, the horn being provided with a curved dielectric closure, the curve of the closure coinciding substantially with the wave-front of the said waves.

6. An electromagnetic horn having a smaller end and a larger flared end, the horn being provided with a dielectric closure providing a closed space between the smaller end and the closure, the horn being waterproof in the said closed space, a coaxial cable connected to the horn and having an antenna projecting into the said closed space, the outer conductor of the coaxial cable being connected to the horn by a waterproof joint, and means for draining the said closed space to keep the coaxial cable and the antenna free of liquid.

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