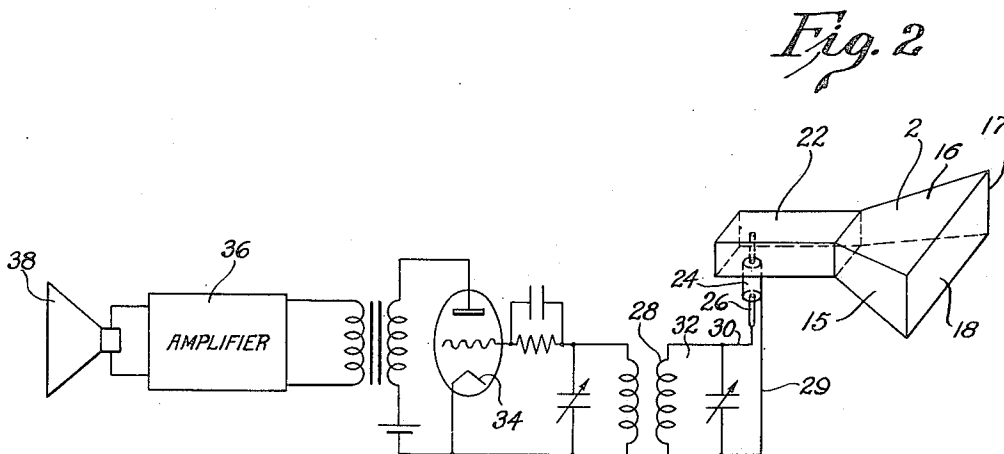
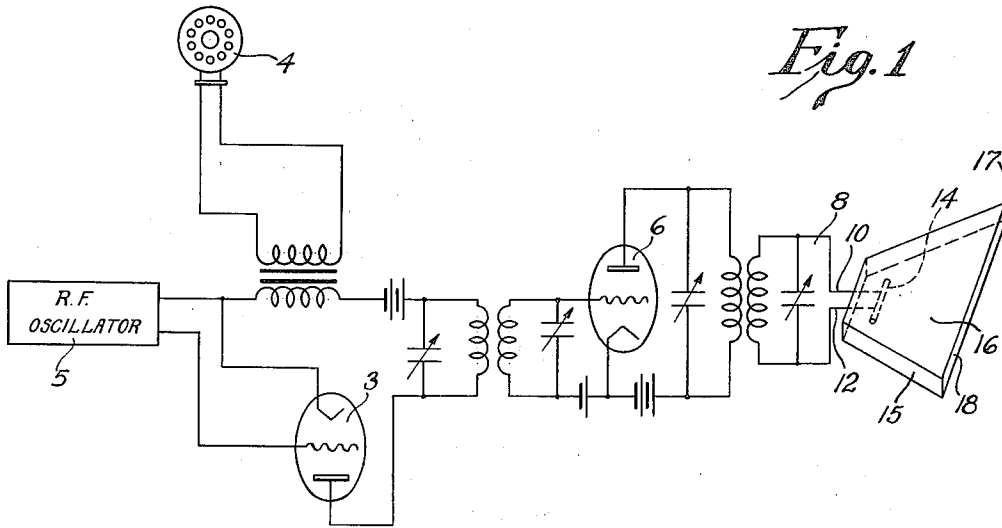


March 28, 1950

W. L. BARROW
ELECTROMAGNETIC HORN

2,501,658

Filed Oct. 12, 1942



INVENTOR
Wilmer L. Barrow
BY *David R. Rude*
ATTORNEY

UNITED STATES PATENT OFFICE

2,501,658

ELECTROMAGNETIC HORN

Wilmer L. Barrow, Concord, Mass., assignor to
Research Corporation, New York, N. Y., a cor-
poration of New York

Application October 12, 1942, Serial No. 461,815

8 Claims. (Cl. 250—33.63)

1

The present invention relates to electromagnetic horns. The present application is a continuation-in-part of application, Serial No. 155,489, filed July 24, 1937, which matured, on August 19, 1947, into Letters Patent 2,425,716.

Beams transmitted from directive antenna systems of any kind, including electromagnetic horns, are usually accompanied by small amounts of radiation in directions other than those intended. These small amounts of radiation are referred to as secondary lobes.

An object of the present invention is to provide a new and improved electromagnetic horn capable of radiating beams the configuration of the field of which inside the horn is such as to produce substantially single-lobe beams.

Another object is to produce substantially single-lobe beams of linear polarization in the radiated wave.

With these ends in view, a feature of the invention resides in a horn that is substantially rectangular in cross section, but with two of the opposite sides of the horn substantially parallel, and with the other two opposite sides flaring. A horn of this configuration is now known as a sectoral horn.

The two first-named sides need not be strictly parallel. Beams substantially free of secondary lobes may be obtained also with the use of pyramidal horns two of the opposite sides of which are substantially, though not quite, parallel. Such horns may be termed somewhat pyramidal, or substantially sectoral.

A further object of the invention, therefore, resides in a new and improved electromagnetic horn of sectoral or substantially sectoral or somewhat pyramidal shape. This novel horn may be used not only for transmission of electromagnetic waves, but also for reception.

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 diagrammatic view of circuits and apparatus adapted for transmission and showing, in perspective, an electromagnetic sectoral horn embodying the present invention, connected to suitable sending equipment; and Fig. 2 is a similar view of a substantially sectoral or somewhat pyramidal horn, connected into circuits adapted for receiving.

A sectoral electromagnetic horn is illustrated in Fig. 1; a substantially sectoral or somewhat pyramidal horn in Fig. 2. Both horns are illus-

2

trated as of substantially rectangular cross section, and are shown flaring smoothly and continuously from a throat or small end of the horn, at the back of the horn, to a mouth or aperture or large end of the horn, at its front. The large end of the horn is electromagnetically open to space to permit the horn to receive electromagnetic waves from space or to radiate electromagnetic waves out into space at the large end. The transverse dimension of the small end of the horn is substantially equal to or slightly greater than the critical transverse dimension for the lowest-order electromagnetic wave that will pass through a hollow pipe of the same cross-sectional shape as that of the small end of the horn.

The principal or central axis of the horn extends between the small and the large ends of the horn. In the case of the sectoral horn, shown in Fig. 1, two of the oppositely disposed sides of the horn, shown as the top and bottom sides 16 and 18, may be parallel, and the other two oppositely disposed sides 15 and 17 flared. In the case of the substantially sectoral or slightly pyramidal horn, shown at 2 in Fig. 2, the sides of the horn corresponding to the parallel sides 16 and 18 of the sectoral horn of Fig. 1 are also flaring, but only slightly. Though not strictly parallel, these two slightly flaring sides 16 and 18 of the horn do not diverge to a sufficient extent to affect substantially the operation that takes place with strictly sectoral horns; the angle between them is still considerably different from the angle between the flaring sides 15 and 17. The slightly flaring sides 16 and 18 of the substantially sectoral or somewhat pyramidal horn will, for convenience, be referred to hereinafter as substantially parallel, to conform to the terminology employed in connection with the sectoral horn illustrated in Fig. 1. As before explained, sectoral and substantially sectoral or somewhat pyramidal horns have the property that they are remarkably free from secondary lobes.

At its throat, the substantially sectoral or somewhat pyramidal horn 2 is shown connected to a hollow-pipe transmission system comprising an elongated hollow-pipe or tubular body portion or section 22 of any desired suitable length. The sectoral horn is shown unprovided with the hollow pipe 22 in Fig. 1. As will hereinafter appear, however, the hollow-pipe system may be employed with the sectoral horn, and the substantially sectoral or somewhat pyramidal horn may be operated without the aid of the hollow-pipe system.

The horn may be constituted of a formed sheet

of conducting material, like metal, such as copper or aluminum, or it may be constituted of other material if its inner wall is otherwise rendered a conductor of electromagnetic waves. The hollow-pipe body portion 22, to which the horn is connected, may be of any desired material, conducting or dielectric, or it may otherwise be provided with an inner conducting wall. It may contain air or other gas, or it may be evacuated.

A projecting metal exciting or absorbing antenna rod 14 or 26 for exciting or absorbing electromagnetic waves may be connected to suitable terminal apparatus either in the throat of the horn or in the hollow-pipe system 22. In Fig. 2, the rod 26 is shown disposed approximately centrally in the hollow pipe 22, substantially at right angles to the axis of the horn 2. In Fig. 1, however, the antenna rod 14 is shown positioned approximately centrally, directly in the throat or small end of the horn. With the antenna 14 positioned in the throat of the horn, as shown in Fig. 1, the pipe portion 22 of Fig. 2 is not needed, for the horn is here directly excited by the antenna 14, without the use of a hollow-pipe transmission line. Substantially the same radiation pattern may be produced with either arrangement. The antenna rod 14 or 26 may, however, be disposed unsymmetrically, in order to yield a modified directive pattern for the radiant energy.

The antenna rods 14 and 26 are shown occupying positions at right angles to each other to yield different types of waves, as hereinafter more fully discussed. Either disposition of the antenna may be employed in either Fig. 1 or Fig. 2, depending upon the wave employed. The invention is not, furthermore, limited to the use of an exciting or absorbing rod 14 or 26. Other radiating or absorbing energy-translating apparatus (not shown), such as a vacuum tube, may also be employed, as described, for example, in Letters Patent 2,307,011 and 2,307,012 issued January 5, 1943.

Either the sectoral horn of Fig. 1 or the substantially sectoral or somewhat pyramidal horn 2 of Fig. 2 may be used either for the transmission or the reception of ultra-high-frequency electromagnetic waves by connecting the terminal apparatus either to sending or to receiving apparatus at a sending or a receiving station. The system of Fig. 1 is illustrated as for transmission and the system of Fig. 2 as for reception, but the horn of either Fig. 1 or Fig. 2 may be connected either to transmit or receive. Sending or receiving apparatus may be connected to the antenna rod 14 or 26 or other exciting or absorbing energy-translating apparatus (not shown). This may be effected, for example, with the aid of conventional balanced bi-conductor, connecting leads 10 and 12, shown in Fig. 1, connected to the exciting or absorbing antenna rod 14, or with the aid of a coaxial-line system 24, 26, shown in Fig. 2, where the conducting antenna rod 26 is shown disposed axially of a conducting tube 24. If the pipe 22 of Fig. 2 is employed in Fig. 1, it may provide a shield for the two-wire line 10, 12. Other connections to the antenna or other translating apparatus may also be employed.

In Fig. 1, there is shown a sending system comprising a radio-frequency oscillator 5, 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. The circuit 8 may be connected to the balanced parallel-line output leads 10 and 12 or the coaxial-line system 24, 26, or it may be otherwise connected to the antenna rod 14 or other translating device.

In the receiving system of Fig. 2, the conducting tube 24 and the antenna conductor 26 are shown respectively connected by a bi-conductor system 29, 30 to a circuit 32 that is coupled by a transformer 28 to a detector 34. The modulated electromagnetic energy received by the antenna 26 will, after demodulation, be amplified by an amplifier 36, and the amplified energy will be evidenced in a loud speaker 38.

With the antenna rod 14 constructed and positioned as illustrated in Fig. 1, substantially parallel to the flat sides 16 and 18 of the horn, and perpendicular to its principal axis, or if the antenna 14 should occupy a position at right angles to that shown, like the antenna 26 of Fig. 2, electromagnetic waves produced by the antenna 14 in the small end of the horn will be transversely polarized; that is, the electric intensity will lie entirely in surfaces normal to the horn axis, or to the direction of propagation. There is, however, a component of magnetic intensity in the direction of propagation of the waves within the horn, even though there is no component of electric intensity in that direction. Waves of this type may be referred to as H waves.

An important mode or wave type is the lowest-order transversely polarized horn wave $H_{1,0}$, with the electric vector mainly parallel everywhere to horizontal direction. This may be obtained with the exciting rod 14 is disposed centrally in the throat of the horn transverse to the axis and in the horizontal plane, as illustrated in Fig. 1, or by feeding an $H_{1,0}$ wave into the throat from a rectangular hollow pipe 22, as illustrated in Fig. 2. This and the $H_{0,1}$ wave type, obtained with the arrangement of the antenna rod 26 shown in Fig. 2, are probably the best for sending a single beam of radiant energy and are the waves most naturally adopted for receiving.

Any of these and many other waves may be propagated with the aid of the sectoral or somewhat pyramidal horn of the present invention, and with remarkable freedom from the secondary lobes. The configurations of the fields of the $H_{0,1}$ and $H_{1,0}$ waves, among others, inside the sectoral horn, are respectively such that the lines of electric-field intensity are everywhere substantially normal to the two parallel sides 16 and 18 of the horn and substantially parallel to said parallel sides. The flaring sides 15 and 17, in the two cases, are respectively substantially parallel and substantially normal to the said lines of electric-field intensity. The result of this configuration is to produce beams of linear polarization in the radiated waves. These waves have constant phase on cylindrical surfaces about the axis within the horn. The substantially sinusoidal variation of the strength of the electric field between the two opposite sides that are parallel to the lines of the electric field is responsible for the relative absence of secondary lobes in the beam.

These waves will not be more fully described herein because they will be understood without further description by reference to a paper by L. J. Chu and W. L. Barrow, entitled, "Electromagnetic Waves in Hollow Metal Tubes of Rectangular Cross Section," Proceedings of the Institute of Radio Engineers, vol. 26, No. 12, December 1938, commencing at page 1520, and also to a paper

by Barrow, entitled, "Electromagnetic-Horn Radiators," Union Radio Scientifique Internationale, No. 79, page 277, containing a revision of a paper presented at the Joint Meeting of the said Union and the Institute of Radio Engineers, at Washington, D. C., April 30, 1938. See also a paper by W. L. Barrow and L. J. Chu, entitled, "Theory of the Electromagnetic Horn," Proceedings of the Institute of Radio Engineers, vol. 27, No. 1, January 1939, commencing at page 51, and also a paper by W. L. Barrow and F. D. Lewis, entitled, "The sectoral electromagnetic horn," Proceedings of the Institute of Radio Engineers, vol. 27, No. 1, January 1939, commencing at page 41.

The ability of the designer to give the relative dimensions of the transverse cross section any set of specified values provides a horn that can produce fan-shaped beams of substantially any shape and of either polarization. For these reasons, the use of sectoral horns is particularly advantageous in certain kinds of applications where the shape of the beam plays an essential role in the operation. In the blind-landing of airplanes, for example, it is desirable, not only that the beam be very sharp, but also that it be peculiarly free from secondary lobes. In one such application, a smooth straight-line intersection is formed between two overlapping beams; systems of this type are commonly referred to as "equal-signal" systems. Horn radiators can provide such smooth overlapping beams without waviness or spurious components that would affect the straightness of this path of intersection. Patterns of this character are useful also in other applications, such as direction-finding and obstacle-detection.

In transmission, modulated ultra-high-frequency energy, in the form of these transversely polarized or other waves, will be taken by the conductors 10 and 12 from the sending apparatus and delivered to the antenna 14 in the throat of the horn. These waves will then be propagated from the horn throat, through the interior of the horn, to the mouth, as horn waves. At the mouth, substantially all of this modulated high-frequency energy will be radiated out into free space by the horn as ordinary electromagnetic radio waves. The horn thus may constitute a directive electromagnetic radiator when used for transmission.

Similar, but reverse, operation will take place for reception. The large end or mouth of the horn is electromagnetically open to space to permit the horn to receive modulated electromagnetic energy from space. The received energy will be guided by the horn to the antenna and the terminal device 24, 26 in the throat, to be delivered to the receiving apparatus.

If it were proposed to transmit with the system of Fig. 2, the receiving system connected to the coaxial system would be replaced by a sending system. The antenna 26 would first excite electromagnetic waves in the hollow pipe 22, and these would be transmitted through the pipe 22 to the throat of the horn 2 and thence propagated through the horn 2 to the mouth as horn waves. At the mouth, substantially all of this energy would radiate into free space as ordinary radio waves, as before described.

The horn operates efficiently to receive substantially all of the incident energy, when used as a receiver; or, when used as a transmitter, to excite waves of the horn type, and thereby to radiate a beam of character appropriate to the

horn rather than to the apparatus and the antenna itself.

Electromagnetic horns should not be confused with reflectors. An electromagnetic horn is provided with guiding surfaces or guiding walls connecting the large end and the small end of the horn that function to guide waves traveling within it and tangentially along its surface in the longitudinal direction, smoothly and without interruption. The guiding walls guide the waves received from space at the mouth of the horn to the throat end of the horn, or they direct, for radiation forward out into space, the waves generated at the small end of the horn.

In the electromagnetic horn, furthermore, the waves travel with a phase velocity substantially different from that of light in the medium of the horn. Near the small end of the horn, the phase velocity may be very much greater than the velocity of light. The phase velocity decreases as the large end or mouth of the horn is reached until, just at or beyond the mouth of the horn, the phase velocity may be exactly the same as that of light.

In the electromagnetic horn, the waves may be regarded as traveling in the dielectric of the space in the horn, continuously outward along the inside conducting horn surface, toward free outer space. The flared horn provides a surface of progressively greater cross-sectional area as the wave travels outward, causing the wave energy to spread over a relatively large area at the mouth for directive transmission, but in such a manner that the wave energy is continuously and smoothly guided and the field configuration of the wave is reasonably maintained during its outward progression. The waves become thus slidingly attached to the inside horn surface, and they remain so continuously attached throughout their sliding movement along this inside horn surface, from the small or throat end of the horn until they reach the mouth of the horn. It is in this manner that they become guided by the surface during such travel outward. Upon arrival at the mouth of the horn, the waves become readily disattached from the horn surface, but they continue thereafter to travel into free space, forward in the desired direction of progression of the waves predetermined by the design of the horn. No such action takes place with wave reflectors.

In receiving, a similar but reverse process takes place.

Though the description above has been specifically with respect to sectoral and slightly pyramidal shapes, the same results may be obtained, with a reasonable degree of accuracy, such as is usable in most engineering applications, with horn shapes that resemble the sectoral or slightly pyramidal. For example, the rectangular cross-section of these shapes may be modified slightly to have round instead of square corners, or a more or less flat or other cross-section of substantially the same shape, without altering materially the radiation pattern and the applicability of the design relations of these specifications.

Though horns provided with straight sides in longitudinal cross-section, as illustrated, are economical and easy to construct, it is to be understood that the invention is applicable also to horns the sides of which may be of somewhat varying curvature. It is the intention of this disclosure and the appended claims to include such modifications of the invention within its

scope. The term "substantially sectoral" will therefore be employed in the claims to include horns of this nature.

The invention is not limited to the exact embodiments thereof that are illustrated and described herein; 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. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding electromagnetic waves received from space at the large end to the small end with a phase velocity substantially different from that of light in the medium of the horn or for guiding to the large end for radiation out into space electromagnetic waves at the small end with a phase velocity substantially different from that of light in the medium of the horn.

2. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, the horn being adapted for the propagation therein of electromagnetic waves having a component of magnetic intensity in the direction of propagation of the said electromagnetic waves within the horn but no transverse component of electric intensity in the direction of propagation of the said electromagnetic waves within the horn, the flaring sides being substantially parallel, and the substantially parallel sides being substantially normal, to the lines of electric intensity of the said electromagnetic waves within the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding the said electromagnetic waves received from space at the large end to the small end with a phase velocity substantially different from that of light in the medium of the horn or for guiding to the large end for radiation out into space the said electromagnetic waves at the small end with a phase velocity substantially different from that of light in the medium of the horn.

3. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, the horn being adapted for the propagation therein of electromagnetic waves having a component of magnetic intensity in the direction of propagation of the said electromagnetic waves within the horn but no transverse component of electric intensity in the direction of propagation of the said electromagnetic waves within the horn, the flaring sides being substantially normal, and the substantially parallel sides being substantially parallel, to the lines of electric intensity of the said electromagnetic waves within the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding the said

electromagnetic waves received from space at the large end to the small end with a phase velocity substantially different from that of light in the medium of the horn or for guiding to the large end for radiation out into space the said electromagnetic waves at the small end with a phase velocity substantially different from that of light in the medium of the horn.

4. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, electromagnetic-wave absorbing or exciting antenna means disposed at the small end of the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding electromagnetic waves received from space at the large end to the antenna means at the small end with a phase velocity substantially different from that of light in the medium of the horn in order that the said received electromagnetic waves may be absorbed by the antenna means or for guiding to the large end for radiation out into space electromagnetic waves excited by the antenna means at the small end with a phase velocity substantially different from that of light in the medium of the horn.

5. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, the horn being adapted for the propagation therein of the lowest order $H_{0,1}$ electromagnetic waves having a component of magnetic intensity in the direction of propagation of the said electromagnetic waves within the horn but no transverse component of electric intensity in the direction of propagation of the said electromagnetic waves within the horn, the flaring sides being substantially parallel, and the substantially parallel sides being substantially normal, to the lines of electric intensity of the said electromagnetic waves within the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding said electromagnetic waves received from space at the large end to the small end with a phase velocity substantially different from that of light in the medium of the horn or for guiding to the large end for radiation out into space the said electromagnetic waves at the small end with a phase velocity substantially different from that of light in the medium of the horn.

6. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, the horn being adapted for the propagation therein of the lowest order $H_{1,0}$ electromagnetic waves having a component of magnetic intensity in the direction of propagation of the said electromagnetic waves within the horn but no transverse component of electric intensity in the direction of propagation of the said electromagnetic waves within the horn, the flaring sides being substantially normal, and the substantially parallel sides being substantially parallel, to the lines of electric intensity of the said electromagnetic waves

within the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding the said electromagnetic waves received from space at the large end to the small end with a phase velocity substantially different from that of light in the medium of the horn or for guiding to the large end for radiation out into space the said electromagnetic waves at the small end with a phase velocity substantially different from that of light in the medium of the horn.

7. An electromagnetic-wave-guide horn of substantially sectoral shape having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides the angle between which is different from the angle between the substantially parallel sides, the horn being adapted for the propagation therein of electromagnetic waves of a predetermined wavelength, the transverse dimensions of the small end of the horn being substantially equal to or greater than the critical transverse dimension for the lowest-order electromagnetic wave that will pass through a hollow pipe of the same cross-sectional shape as that of the small end of the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between its large end and its small end for guiding the said electromagnetic waves from space at the large end to the small end with a phase velocity substantially different from that of light in the medium of the horn or for guiding to the large end for radiation out into space the said electromagnetic waves at the small end with a phase velocity substantially different from that of light in the medium of the horn.

8. An electric system having, in combination, an electromagnetic-wave-guide horn substantially rectangular in cross-section and having a small end and a large end, the horn being of substantially sectoral shape and having a pair of oppositely disposed substantially parallel sides and a pair of oppositely disposed flaring sides, the large end being electromagnetically open to space

to permit the horn to receive electromagnetic waves from space or to radiate electromagnetic waves out into space at the large end, electromagnetic-wave absorbing or exciting antenna means disposed at the small end of the horn, the horn being provided with means comprising electromagnetic-wave-guiding walls between the large end and the small end for guiding the said electromagnetic waves received from space at the large end to the antenna means at the small end with a phase velocity substantially different from that of light in the medium of the horn in order that the said received electromagnetic waves may be absorbed by the antenna means or for guiding to the large end for radiation out into space electromagnetic waves excited by the antenna means at the small end with a phase velocity substantially different from that of light in the medium of the horn, and means for connecting the antenna means with means for evidencing the said received electromagnetic waves absorbed by the antenna means or with means for energizing the antenna means to excite at the small end the said electromagnetic waves to be radiated out into space.

WILMER L. BARROW.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
435,996	King	Mar. 24, 1942
1,653,796	Wolff	Dec. 27, 1927
2,130,913	Tolson	Sept. 20, 1938
2,206,923	Southworth	July 9, 1940
2,255,042	Barrow	Sept. 9, 1941
2,283,935	King	May 26, 1942
2,297,202	Dallenbach et al.	Sept. 29, 1942

FOREIGN PATENTS

Number	Country	Date
841,036	France	Jan. 28, 1939