Jan. 9, 1951

P. W. KLIPSCH

LOUD-SPEAKER HORN

2,537,141

Filed June 15, 1945

2 Sheets-Sheet 1

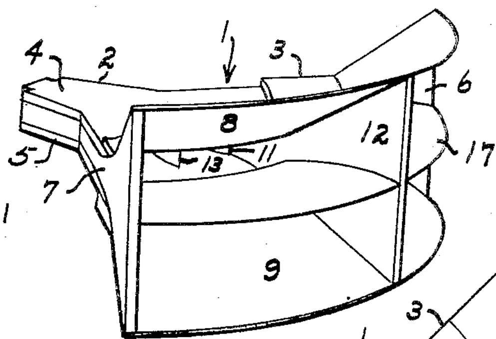


Fig. 1

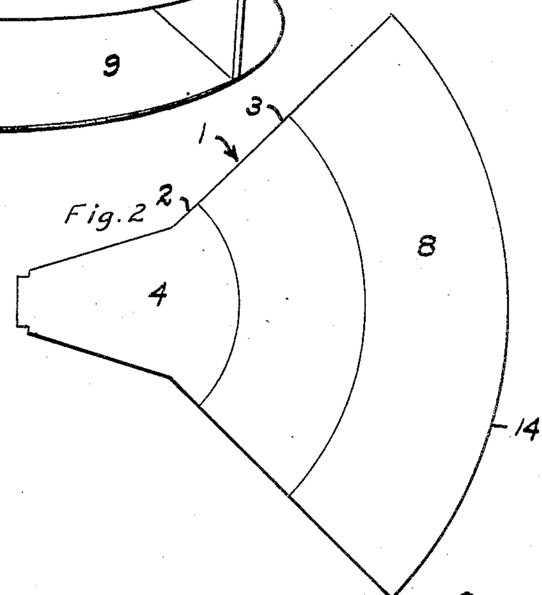


Fig. 2

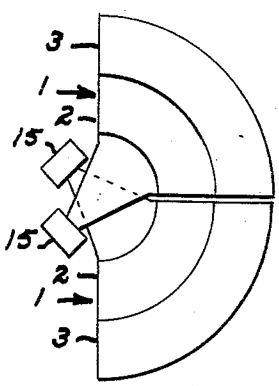


Fig. 8

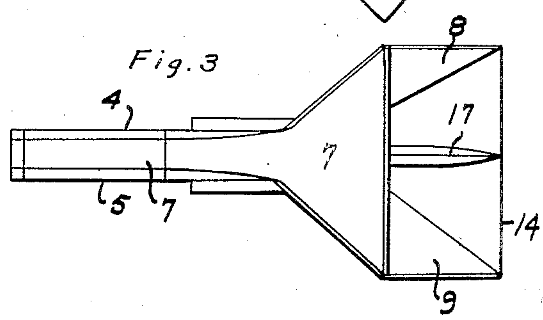


Fig. 3

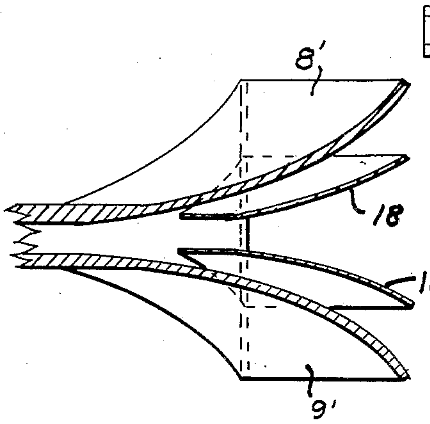


Fig. 7

PAUL W. KLIPSCH

INVENTOR.

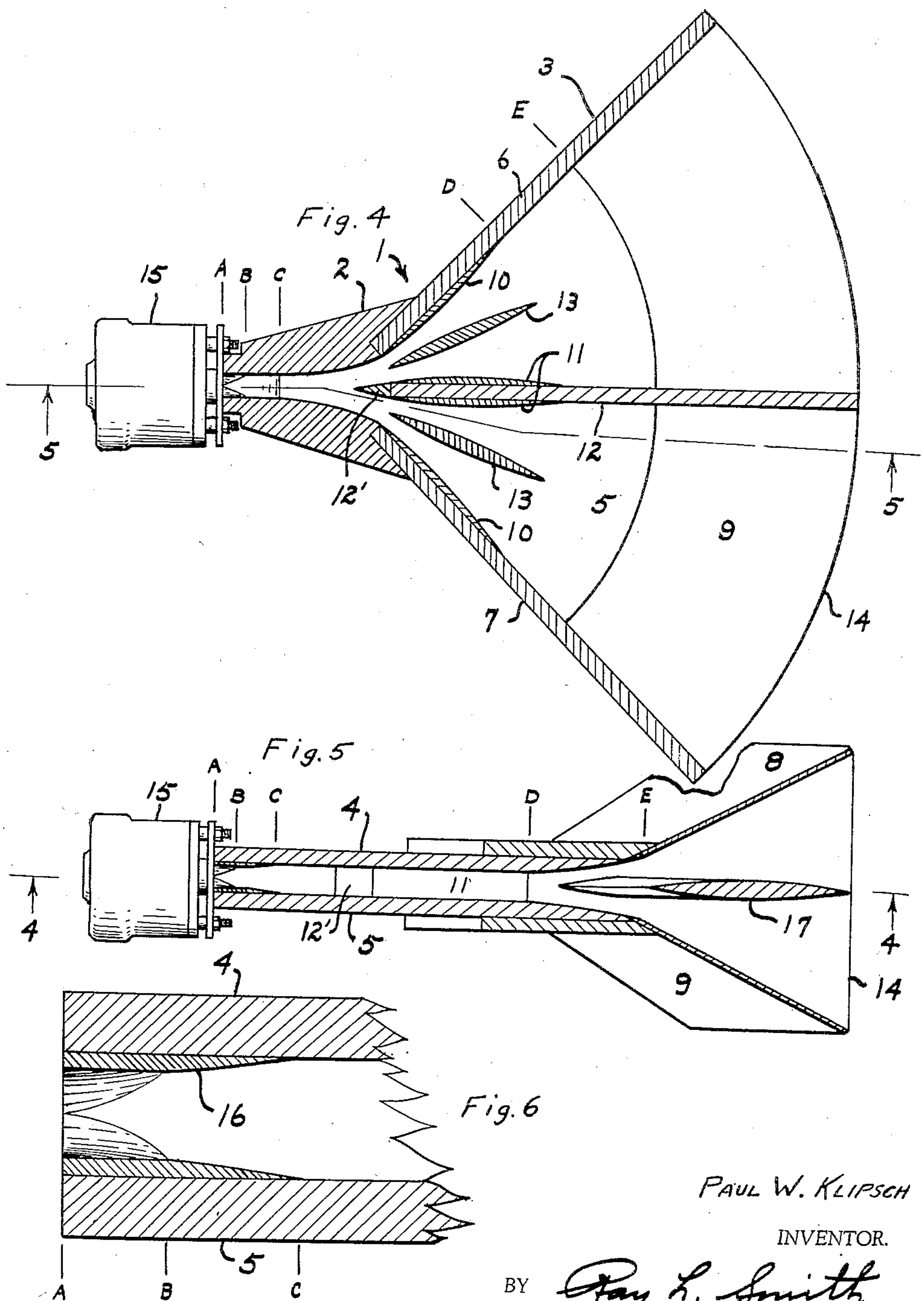
BY Ray L. Smith

ATTORNEY.

Jan. 9, 1951 P. W. KLIPSCH 2,537,141

LOUD-SPEAKER HORN

Filed June 15, 1945 2 Sheets-Sheet 2



PAUL W. KLIPSCH

INVENTOR.

BY Ray L. Smith

ATTORNEY.

Patented Jan. 9, 1951

2,537,141

UNITED STATES PATENT OFFICE

2,537,141

LOUD-SPEAKER HORN

Paul W. Klipsch, Hope, Ark.

Application June 15, 1945, Serial No. 599,642

6 Claims. (Cl. 181—27)

1

The invention relates to horns for loudspeakers, particularly to those intended for the middle and high audio frequencies and for the achievement of specified wide angles of radiation.

One object of the invention is to provide a horn for the high frequencies to complement the low frequency horn or "Woofer" disclosed in U. S. Patent No. 2,310,243 issued February 9, 1943, and Patent No. 2,373,692 issued April 17, 1945, the required complementary performance being that of transmitting the frequency range from about 400 cycles per second and higher and radiating into an angle about 90° wide and a solid angle of $\pi/2$ steradians.

Broadly, an object of the invention is to provide a horn of desired angular radiation in the smallest possible length and space commensurate with the requirements of mouth size, throat size and taper rate, at the same time maintaining such bends as are necessary to minimum angles and to place them at regions in the conduit where the radii of the bends can be kept small and the bend curvature smooth.

A specific object is to provide a horn in which expansion takes place in a single plane for a portion of the horn length to bring the radiation angle up to the desired limits in this plane, then expansion takes place at right angles to said first plane while continuing to expand in the wedge angle reached in the first expansion. Expansion continues until the desired mouth area is accomplished.

Another object is to provide a horn having cooperating side walls and baffles so constructed and arranged that the radiation angle of the horn is determined by the outer surface boundaries or walls of the horn nearest the mouth.

It is also an object to provide a horn of the class described including at least one set of cell baffles which terminate short of the mouth of the horn whereby the individual cell mouths are small compared to the shorter wave lengths to be radiated.

The foregoing are primary objects which, together with other objects and advantages will be more fully apparent from the following description taken in connection with the accompanying drawings in which—

Fig. 1 shows an oblique perspective view of one embodiment of the invention;

Figs. 2 and 3 show respectively top and side exterior views of the horn shown in Fig. 1;

Fig. 4 is a horizontal sectional view of the horn taken on line **4—4** in Fig. 5, the driving motor being shown attached thereto;

2

Fig. 5 is a vertical sectional view of the horn taken on line **5—5** in Fig. 4;

Fig. 6 is an enlarged sectional view of the portion proximate the throat and illustrates how the taper progresses from circular to rectangular section in a short length;

Fig. 7 shows one possible alternative of baffle arrangement at the mouth; and

Fig. 8 shows two units with motors attached, so arranged as to give 180° radiation angle.

It should be understood that the terms "top" and "side" are used to simplify terminology and not to imply any limitation in the positions in which the horn or horns may be used.

Generally speaking, and subject to several limitations, the radiation angle of a horn is determined by the angle formed between the outer surface boundaries or walls of the horn nearest the mouth. Roughly, extrapolation of the walls of the horn outward into space will define the radiation angle. However, this general idea holds only if suitable deflectors within the horn force the sound to follow the curves of the outer horn boundaries and is further subject to limitations relative to mouth size. In the prior art the multicellular horn consists of a cluster of small horns, all identical, and grouped to direct the sound throughout a given solid angle; such a horn is shown and discussed by Wente and Thuras "Auditory Perspective—Loudspeakers and Microphones," Electrical Engineering, January 1934, pages 17–24. An example of an asymmetrical multicell is that taught by the Wente Patent No. 2,135,610, in which expansion takes place simultaneously at different rates in two planes, and the directive properties in one plane as well as expansion rate are controlled by inserted deflectors.

The limitations of directivity arise from the relation of mouth size to the transmitted wave length and many other factors. H. F. Olson, in his book, "Elements of Acoustical Engineering," McGraw-Hill, 1940, discusses directional characteristics and gives an excellent bibliography of the whole subject. From this and other sources, it becomes evident that ideal directional characteristics can only be approached. From the published discussions of multicell horns the limitations of total mouth size, individual cell size, angle between cells and the taper rate will be realized. In the various attempted designs to achieve specifically a high frequency speaker to supplement the aforementioned woofers, the applicant soon found that the conventional multicell does not lend itself to the shapes necessary for the desired angular characteristics. The present invention comprises a pronounced improvement thereover and more closely approaches the desired ideal.

The present invention contemplates a multicellular arrangement in which at least one set of cell baffles terminates considerably short of the mouth, whereby the individual cell mouths are small compared to the shorter wave lengths to be radiated so that a small number of such baffles can suffice and still function as true deflectors. In the conventional symmetrical multicell, the separate cells tend to act as separate horns at the higher frequencies with resultant formation of sharp beams. By continued subdivision this could be avoided but is deemed impractical by Wente and Thuras in their paper already referred to on "Auditory Perspective"; their remarks on "The High Frequency Horn," pages 21–22, apply. This impracticality can be avoided by the present invention. It should be pointed out that, once the wave front has been formed to the desired radius of curvature, the wave acts as its own guide, needing no further deflectors.

The aforementioned low frequency speaker, designed to operate in a room corner, radiates into substantially $\pi/2$ solid angle. Ideally, the supplementary high frequency speaker should radiate into the same angle for several reasons, two or which are: first, to get adequate coverage over the normal listening region; and second, to give the same intensity level as the woofer. By way of explanation of the second point, it is pointed out that well designed horns will display 25% to 50% efficiency. Hence, assuming the low frequency horn and the high frequency horn to deliver about the same efficiency, they should radiate into the same solid angle to give the same intensity, that is to say, to prevent concentration of sound by one speaker into a smaller angle than that into which the other speaker radiates.

Ideally both speakers will have the same directivity characteristics throughout the frequency range of each. Generally speaking this is impossible except in prohibitively large structures. But, if the directivity and frequency response characteristics approach reasonably close to the ideal, there should be no necessity to equalize either channel nor the system as a whole except perhaps at the extreme low and high ends of the spectrum.

The present invention as shown in the embodiment of Figs. 1 to 6 comprises the horn structure **1** having two regions of expansion generally indicated at **2** and **3**, of which the former extends from point B to point D while the latter extends outwardly from point D. The region **2** comprises a pair of parallel top and bottom walls **4** and **5** and side walls **6** and **7** perpendicular thereto and extending divergingly outwardly so that expansion in this region takes place in a single plane and brings the radiation angle up to the desired limits in this plane. In the region **3**, beyond D, the divergence of the side walls **6** and **7** is constant but the walls **4** and **5** merge into converging top and bottom walls **8** and **9** which determine the radiation angle in a vertical direction.

It seems apparent from reference to Fig. 4 that the expansion in the region **2** extending from C to D takes place all in one plane, without expansion at right angles to such plane. Attention is also directed to the fact that the terminal portion of this region includes the cell baffles to which reference is above made.

These comprise a central baffle **12** of which the rearward portion **12'** provides an initial bifurcation and gentle lines of curvature forwardly from the throat. Proximate the forward end of the baffle portion **12'** each air column is again bifurcated by means of contour surfaces **10** on the sidewalls **4** and **5** and similar surfaces **11** on the central baffle **12** cooperating with deflectors **13**. This construction provides desired deflectors for the sound waves and also desirably controls the flare rate.

From the region D to the mouth **14**, expansion continues at the angle established in region C—D in the plane shown, and expansion commences in the plane at right angles thereto. Fig. 5, the view taken at right angles to that of Fig. 4, shows one way of treating the mouth section to obtain a desired angle, namely 60° in a given length, and shows also the non-expansion in the C—D regions in this plane. It is to be noted that the structure as shown in this figure includes a single horizontal baffle **17** whereas the structure shown in the alternate structure of Fig. 7 comprises curved baffles **18** cooperating with surfaces **8'** and **9'** which are curved complementarily.

The expansion from the throat section at A, to section B, may take place in any convenient manner, for example, for a driving motor **15** with circular throat, the expansion should be from the circular throat to a square cross section by providing an inner filler member **16** secured to the inner walls and having the configuration as shown in Fig. 6, and then to whatever size rectangular section may be chosen at section C.

In the particular design shown, the cross section at C is one inch square which results in a very small difference between minimum and maximum path lengths through the first "bend" or rather, gentle curve. This design provides a minimum of interference at the point where the divided cellular air columns rejoin. Theoretically the horn shown should operate effectively throughout the upper portion of the audible register. Listening tests and microphone measurements indicated uniform field within the contemplated angles.

It is not to be expected that the horn of the present invention would improve upon the angular radiation characteristics of an ideal multicell horn of equivalent mouth and outer wall conformation; rather, the present invention aims (1) to make possible a nearer approach to ideal mouth and wall conformation for wide angle radiation with limited horn lengths and (2) to hold the phase of radiation over different parts of the mouth area such that the wave front is a spherical surface with the location of its center as invariant as possible with respect to frequency. That is to say, the present invention recognizes the impossibility in a symmetrical multicell of attaining uniform wave phase at the surface where the cell joins the non-cellular parts of the horn except when the total angle of radiation is limited, and hence the waves do not emit from the mouths in phase. The greater the angle of radiation, the larger the phase difference, on the one hand, and on the other hand, the shorter the available length of horn, the larger the phase difference. In the present invention, the ideal emitted wave surface and desired outer wall angle is attainable to a practical degree, in a considerably shorter length of horn. An attempt to design a conventional multicell of the same length and cut-off as the horn illustrated herewith resulted in either poor phasing of the wave fronts in the individual cells or else a smaller angle of radiation than desired.

The terms "multicell," "conventional multicell," "multicellular horn," etc., are used herein to mean the type of horn depicted in Fig. 2.11 of the hereinbefore referred to "Elements of Acoustical Engineering," by Olson. The term "asymmetrical multicell" is used to designate the type of horn described herewith, or such a horn as described in the aforementioned Wente Patent No. 2,135,610 wherein the cell mouths are not square, and the cell axes are not necessarily straight.

This speaker was specifically designed to operate with the aforementioned "Woofer." The woofer dimensions (see Journal of the Acoustical Society of America, vol. 13, No. 2, pp. 137–144, October 1941, also vol. 14, No. 3, pp. 179–182, January 1943 as well as Patent No. 2,373,692) are approximately, length, diagonal from corner, 28''; with across wings, 39''; and heighth 39''. The frequency response is roughly from 40 to 400 cycles. The cross-over network crosses at 400 cycles. In order to cover the same radiation solid angle as the woofer, and also to obtain the desired angular coverage, the horizontal and vertical angles for the H. F. horn were selected as respectively 90° and 60°. The space limited the cut-off frequency to 330 cycles when using a Western Electric 555 W driving motor with approximately 0.40 square inch throat area. With this throat size, available length, and given flare-cut-off, the mouth size available is about 240 square inches, more than adequate to prevent severe reflections at 400 cycles, and sufficient to give the desired directional properties. The drawings are roughly to scale, the length of horn from throat fitting to mouth being approximately 21 inches. For the pilot model most of the walls are of plywood. The deflectors are of soft pine. The mouth arrangement of Fig. 5 was chosen as the easiest to construct as well as giving the desired vertical spread. The application of a coat of varnish serves to harden the soft wood surfaces and prevent surface absorption of the higher frequencies.

In the experimental model the sectional wall thickness was built up by gluing 2 sheets of ½ inch plywood together and then rasping to the desired contour to give th desired vertical expansion through the D—E region, and from E to the mouth, ⅛ inch ply material known in the building trade as "Tekwood" was used to generate the two conical surfaces which are best delineated in Fig. 1. As a manufactured product the entire top and bottom surfaces would better be molded, say, from a post-forming plastic sheet, or perhaps from wood plies laid in a suitable mold and bonded in the desired contour by the fluid pressure method and high-frequency heating.

The foregoing details are intended to disclose the invention in a manner to enable the skilled artisan to construct a horn embodying the invention, but are not to be implied as limitations on the claims. Obviously, almost any angular limits can be met, and the wider the angle, the greater will be the advantage of the present invention over the existing art. Any feasible construction method may be employed, and any rigid materials may be used, such as wood, metal or plastic.

I prefer to place the horn cut-off as far as possible below the crossover frequency, and to place about 18 decibels to 30 decibels per octave loss in the attenuation region of the high pass filter to keep the electrical power fed to the speaker below its cut-off frequency as low as possible, as suggested in "Woofer-Tweeter Crossover Network," Electronics—Nov. 1945, pp. 144–145. This prevents driving the diaphragm through large excursions in the frequency range where little or no acoustic loading exists. If large diaphragm excursions in a 330 cycle horn should occur, say, at 200 cycles, harmonics of this frequency would be generated and the harmonics would propagate through the horn resulting in rough performance. The low pass part of the crossover network needs only, say, 6 decibles per octave attenuation above crossover. In a horn of the length, cut-off frequency, and mouth size described, the cut-off of 330 cycles permits adequate loading to occur at and about the crossover frequency (400 cycles) so that very little distortion occurs. The questions of harmonic generation by allowing appreciable power below the horn cut-off frequency to reach the voice coil are discussed in copending application 586,786 filed April 5, 1945, now abandoned, and also in a paper "A Note on Acoustic Horns," by Paul W. Klipsch, Proc. I. R. E., July 1945.

The bends, or rather gentle curves, in the horn are located such that the bending of the air column occurs where the length of the wave front transverse the bend is less than ½ wave length at 10,000 cycles. The design relative to such bends is in keeping with best practice so that performance up to 10,000 cycles is limited only by the driving unit employed.

The taper law employed in the particular design shown is exponential, chosen as being the most economical of the total and critical space available. Obviously, however, the novel features of the present invention may be applied to a horn employing any taper law or combination of taper laws such, for example, as the hyperbolic law taught by the Salmon Patent No. 2,338,262, or the multiple taper scheme described by Olson, "A Horn Consisting of Manifold Exponential Sections," Journal of Society Motion Picture Engineers, vol. 30, pp. 551, (1938).

Expansion first in a single plane and then in both planes results in a considerably greater latitude in design, permitting the choice of horizontal and vertical radiation angles independently of each other. Angles other than those described and illustrated herein are readily attainable by this novel arrangement of expansion. The resultant "astigmatism," or fact that the wave front radius of curvature in the vertical plane differs from that in the horizontal plane, does not appear to be a defect from either a theoretical nor practical standpoint.

Broadly the invention comprehends a loud speaker horn of which the component parts are so constructed and arranged that desired angular radiation is provided in the smallest possible length and space commensurate with the requirements of mouth size, throat size and taper rate.

What is claimed is:

1. In a loudspeaker horn, an enclosure forming an air column shape characterized by means forming successive bifurcations whereby the air column is first diverted in a region of small area and with smooth gradual curves into two air columns symmetrically spaced from the original axis by a given angle, and outwardly therefrom each of said air columns is again bifurcated in the same plane as the first bifurcation to give a

further angular spread to the emitted wave, and means outwardly from said first means and extending transversely thereof forming additional bifurcations whereby the radiation angle of the horn is determined by the surface boundaries or walls of the horn nearest the mouth thereof.

2. A horn for middle and upper audio frequencies comprising means forming a first length of air column which expands substantially in a first single plane, said means including deflectors to diffuse the sound to the desired angular spread in said plane, said deflectors terminating at an arc where the wave front has been caused to acquire the desired angular spread, means forming a further length of air column having its longitudinal axis in alignment with the longitudinal axis of said first length of air column and in which expansion continues at the same angle in the first plane as established in said first length of air column and also expands in a plane perpendicular to said first plane, and means comprising at least one additional deflector in said further length of air column for diffusing the sound in said second plane.

3. A horn for middle and upper audio frequencies comprising means forming a first length of air column which expands substantially in a first single plane, said means including deflectors to diffuse the sound to the desired angular spread in said plane, said deflectors terminating at an arc where the wave front has been caused to acquire the desired angular spread, means forming a further length of air column in which expansion continues at the same angle in the first plane as established in said first length of air column and also expands in a plane perpendicular to said first plane, and means comprising at least one additional deflector in said further length of air column for diffusing the sound in said second plane.

4. In a loudspeaker horn, solid means forming two opposite boundaries which are flat and substantially parallel in a first region near the throat whereby substantially no expansion occurs

to flare of said boundaries in such first region and which are curved outwards from each other and flaring in a second region farther from the throat, solid means forming two other opposite boundaries forming with said first boundaries a conduit, said second means comprising an assembly of curved and flat members forming flare in the region near the throat at a predetermined rate and at a fixed included angle, and contoured pieces fixed to said flat parts to form a smooth curve and expansion with the initial curve.

5. A loudspeaker horn in accordance with claim 4 in which the contoured pieces fixed to said flat surfaces are terminated within said horn and short of the horn mouth so that the individual cell mouths formed by said contoured pieces and the outer walls of the horn are small in size, preferably small compared to the shortest wavelength to be transmitted by said horn.

6. A loudspeaker horn in accordance with claim 4 in which the axis of the conduit formed by said boundaries constitutes a single straight line.

PAUL W. KLIPSCH.

REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
1,067,905	English	July 22, 1913
1,477,556	Grissinger	Dec. 18, 1923
1,525,320	Pierce	Feb. 3, 1925
1,614,983	Fuller	Jan. 18, 1927
1,666,057	Grissinger	Apr. 10, 1928
1,666,058	Grissinger	Apr. 10, 1928
1,666,059	Grissinger	Apr. 10, 1928
1,992,268	Wente	Feb. 26, 1935
2,001,089	Blattner	May 14, 1935

FOREIGN PATENTS

Number	Country	Date
281,792	Great Britain	Dec. 15, 1927