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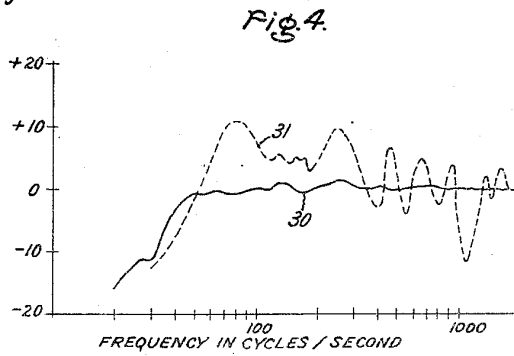
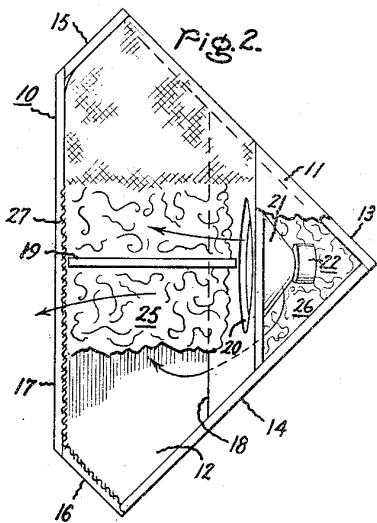
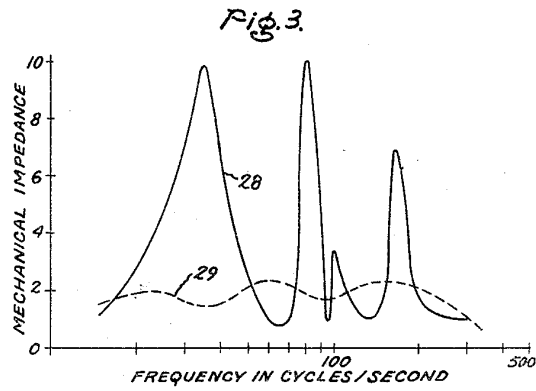
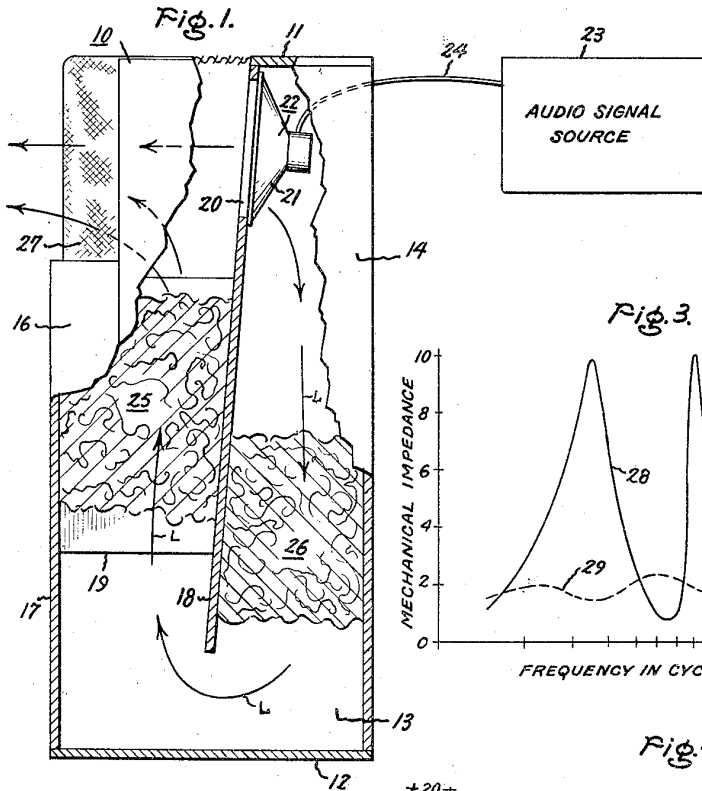
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2,765,864

ACOUSTIC HORN ASSEMBLY

Filed March 14, 1955

2 Sheets-Sheet 1



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Fig. 5.

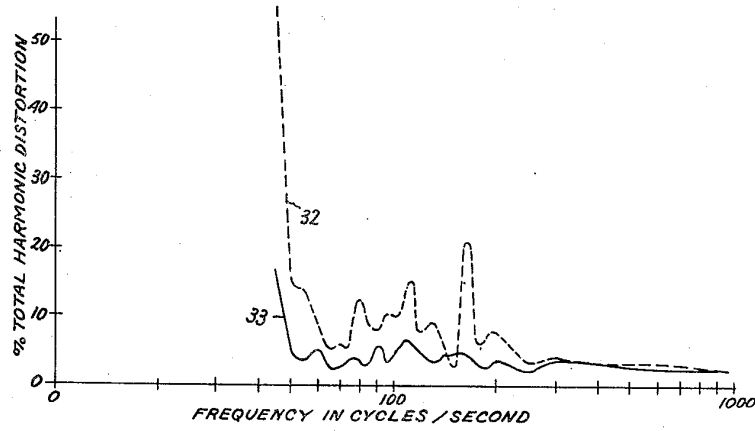
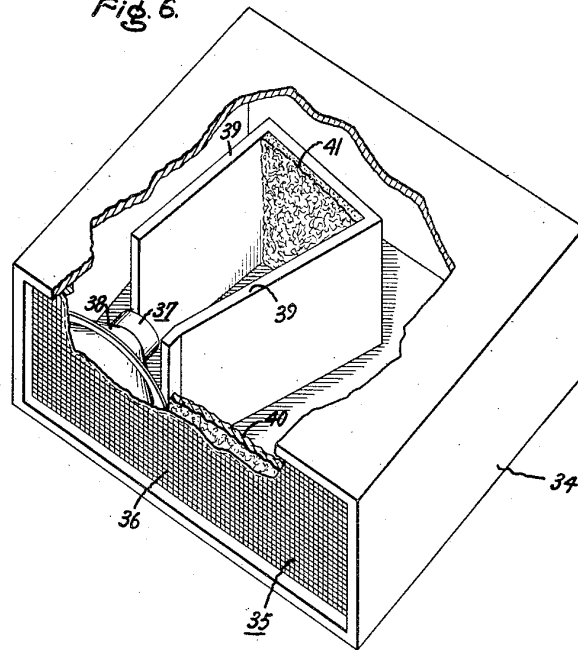


Fig. 6.



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ACOUSTIC HORN ASSEMBLY

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Application March 14, 1955, Serial No. 494,159

7 Claims. (Cl. 181—31)

This invention relates to acoustic horn assemblies which are suited for utilization in combination with an acoustic diaphragm such as that commonly utilized for a loud speaker. While this invention is subject to a large number of modifications and variations, it is ideally suited for utilization with a conventional loud speaker and is particularly described in this connection.

It is known that the response of an acoustic diaphragm and/or loud speaker assembly is a function not only of the speaker structure itself but also of the accompanying speaker enclosure. In order to obtain faithful reproduction of low frequency sound waves, the sound waves formed on the back side of the acoustic diaphragm of the speaker or transducer may be passed through a horn of increasing cross-sectional area. Such horns are satisfactory for high fidelity sound reproduction but best results are achieved only with a horn of such length as to be very cumbersome even though the horn is composed of labyrinth convolutions within the speaker enclosure or cabinet.

An important characteristic of horns is that their transformer-like property improves the impedance match between the speaker and air, particularly at low frequencies. This results in a significant reduction in the speaker excursion or motion for a given sound energy output and, consequently, less distortion.

At low frequencies, the size of the mouth of the horn is necessarily relatively short compared to a wave length. Consequently, the acoustical impedance of the air load does not match the impedance of the mouth of the horn. A condition then results which is somewhat analogous to that of a transmission line which is not terminated in its characteristic impedance. Since, under these conditions, the energy is not all absorbed at the mouth, some of it reflects back down the horn and tends to either reinforce or cancel the original signal. This results in large fluctuations, with changing frequency, in the impedance at the throat of the horn and a resulting non-uniform frequency response. In addition, these fluctuations in horn throat impedance result in a high excursion of the speaker diaphragm at certain frequencies and distortion.

It is therefore an important object of this invention to provide an acoustically loaded horn assembly having a substantially flat frequency response with any desired degree of sharp cutoff.

Another object of this invention is to provide an improved acoustical horn.

An additional object of this invention is to provide an acoustical horn assembly which for a given level of sound quality occupies a smaller space for a given frequency response and distortion than do horn-type assemblies previously known.

It is also an object of this invention to provide a combination acoustical horn and acoustical diaphragm assembly.

An additional object of this invention is to provide an

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acoustical horn assembly which is effectively terminated in its characteristic impedance.

In accordance with an aspect of this invention there is provided an improved acoustic horn assembly in which an acoustical horn has an increasing cross-sectional area from the throat of the horn to the mouth of the horn. Between the throat and mouth of the horn acoustic loading means are interposed to obtain a desired frequency response which may include a substantially flat low distortion output with a sharp cutoff. In a specific embodiment the horn is effectively terminated in its characteristic acoustical impedance as seen from the throat of the horn.

In an exemplary embodiment of this invention the throat of the horn is coupled to the back radiating side of an acoustic diaphragm and the mouth of the horn is oriented in proximity to the front radiating face of the acoustic diaphragm so that the high frequency sound components are radiated by the front side of the acoustic diaphragm and the low frequency components are radiated by the horn with substantially no reflections from the mouth of the horn.

Other important objects and aspects of this invention will become apparent from the following description particularly when taken with the annexed drawing in which Figures 1 and 2 illustrate a side elevation and top view of a preferred embodiment of this invention; Figures 3, 4 and 5 illustrate characteristic response curves useful in explaining operating characteristics obtainable with the practice of this invention and Figure 6 illustrates an alternative embodiment of this invention.

In accordance with the practice of this invention an acoustical horn is loaded with acoustical impedance material so that the horn appears from the throat end to be terminated in its characteristic impedance. Thus, the impedance loading of the acoustical horn is essentially resistive and of a magnitude substantially equal to the characteristic impedance of the horn.

It may be shown that a sound radiator that is small compared to a wave length has a relatively flat frequency response with a substantially constant driving force if it is mass loaded. It is also known that if the radiator is resistance loaded the output tends to increase approximately 6 decibels per octave as the frequency is increased. Therefore, a terminated horn with a mouth which is small compared to a wave length will have an output which increases approximately six decibels per octave as the frequency increases.

In order to compensate for the tendency of the horn to emphasize the high frequency audio components more than the low frequency components additional electrical or mechanical compensation must be provided. Mechanical attenuation can take the form of masses of sound absorbing material located in at least one region throughout the length of the horn so as to provide the necessary high frequency compensation to result in substantially flat horn output. This form of mechanical compensation is more satisfactory than the electrical compensation, since it avoids the necessity of utilizing complicated circuitry, by stuffing portions of the horn with sound absorbent material. In addition, this form of acoustical loading decreases the effect of harmonic distortion occurring at the throat of the horn.

Applying these fundamental relations to a specific example, it may be assumed that there is provided a loud speaker with a horn coupled to the back radiating surface of the speaker. The mouth of the horn is located in the vicinity of the front radiating face of the speaker. In order to prevent impedance fluctuations throughout the frequency response range of the speaker it is necessary to terminate the horn resistively in the characteristic impedance of the horn.

Therefore, a way of making up the natural tendency of the horn to increase the amplification of high frequency components approximately 6 decibels per octave is to design the horn so that the sound output of the horn at cutoff approximately matches the front radiation from the speaker at high frequencies and to distribute the loading material in the horn so that it will attenuate the high frequency components approximately 6 decibels per octave.

In accordance with a preferred embodiment of this invention there is provided the structure illustrated in Figures 1 and 2 wherein speaker cabinet assembly 10, which is adapted to be placed in the corner of a room, includes top member 11 and bottom member 12 with side panels 13 and 14. The enclosure is completed by vertical strips 15 and 16 which are rigidly secured together by panel 17. Supported from the side panels and the top panel is baffle 18 which is rigidly secured to front panel 17 by baffle member 19. Opening 20 is provided in baffle 18 and acoustic diaphragm 21 of electroacoustic transducer assembly 22, for example a loud speaker, is mounted across this hole. A source of audio signals 23 is coupled by lead 24 to the speaker 22. In accordance with the practice of this invention sound absorbing material 25 terminates the end of the horn and provides distributed impedance throughout the length of the horn. In addition, a second region 26 of sound absorbing material is provided in the horn.

In accordance with the practice of this invention high frequency components are radiated by the front surface of acoustic diaphragm 21 and out through opening 27. Low frequency components from the back surface of the acoustic diaphragm, indicated by the arrows L, pass through the horn of expanding cross section and emerge through opening 27. The masses of sound absorbing material 25 and 26 effectively attenuate the high frequency components of the audio input approximately 6 decibels per octave and the mass of sound absorbing material 25 also provides a resistive termination for the horn approximately equal to the characteristic impedance of the mouth of the horn. The mass of sound absorbing material 25 replaces the mass of air of an equivalent longer horn and results in a considerable volume saving since the mouth end of the horn occupies the larger volume.

With loading material distributed in the horn, such as that in Figures 1 and 2, it is apparent that the horn passes frequencies at which the path length through the

By way of example, design criteria, which may be utilized in the practice of this invention, appear in the succeeding paragraphs and characteristic response curves obtained with the practice of this invention appear in Figures 3 to 5.

The excursion of the acoustical diaphragm for a given sound input is reduced by the use of a horn. It can be shown that this reduction is approximately equal to the ratio of the horn mouth area to the horn throat area and that to obtain significant improvements by the use of a horn rather than a reflex enclosure, this ratio should be of the order of or less than one to six.

The throat area should be chosen so that the mechanical impedance of the horn is lower than the mechanical impedance of the speaker at the lower cutoff frequency of the system. For impedance match, it may be shown that the horn throat area A in square feet is approximately defined by:

$$A = 112 C_n f_c R_o^3 \quad (1)$$

where C_n is the suspension compliance of the acoustical diaphragm in centimeters per dyne, f_c is the low frequency cutoff of the horn and R_o is the effective speaker radius in inches. For example, if the speaker has a mechanical compliance of 5×10^{-7} centimeters per dyne, a typical value, then the throat area in square feet is:

$$A = 5.6 \times 10^{-5} f_c R_o^3 \quad (2)$$

The throat area should, therefore, be this value or smaller.

The horn mouth area is determined by the necessity of matching the output of the horn at cutoff to the high frequency output of the speaker. This condition is satisfied if:

$$A_m/A = (f_r/f_c)^2 \quad (3)$$

where A_m is the horn mouth area, A is the throat area, f_r is the speaker resonant frequency and f_c is the effective low frequency cutoff of the horn.

The effective horn cutoff frequency for a terminated horn with a mouth to throat area ratio of 6 to 1 is about 1.6 times the cutoff frequency of an infinite horn. Taking this approximation into consideration, the distance in which the horn must flare a factor of two in area can be given.

Using the above criteria some typical design characteristics of horns in accordance with this invention appear in Table I.

Table I

Speaker Diameter	Speaker Resonance Frequency, Cycles per sec.	A in sq. ft. from Equation 1	Mouth Area A_m in sq. ft.	Throat Area A_t sq. ft.	Horn Cutoff, C. P. S.	Horn Vol. in cu. ft.	Approx. Acoustic Power at 40 C. P. S.
8''	100	.18	1.15	.18	40	3.2	.04
10''	90	.57	2.9	.47	40	8	.1
12''	70	1	5.4	.90	30	20	.2
12''	70	1.3	4.0	.67	40	10.5	.4
15''	40	2.5	6.4	1.05	25	28	.8
15''	40	3.0	5.4	.90	30	20	1
15''	40	4.0	4.0	.66	40	11	2

horn in a wave length or more. It will be apparent that this results in serious fluctuations in the frequency response at high frequencies due to cancellation or addition of the front radiation of the speaker 21 and the sound coming through the horn. Consequently, it is generally necessary to place padding material in at least two regions along the horn so that the horn acts effectively as a sharp cutoff acoustic filter with a high frequency cutoff which is just below the frequency at which the length of the horn is one wave length.

In this manner, faithful reproduction of the high frequency components of the audio input and of the low frequency components of the audio input is obtained.

It will be noted that the volume given is approximately the minimum volume for an ideal exponential horn. It will be appreciated that the actual volume will be somewhat larger than this because of the volume occupied by the materials utilized to form the speaker enclosure and the waste space involved in folding an expanding horn into a reasonably shaped enclosure.

It will be noted that Table I lists the approximate acoustic power in watts that will be available at 40 cycles per second from typical commercially available speakers in the enclosures indicated by the table. This is about 36 times the power available from the same speaker when mounted in an infinite baffle.

It will be noted that for large speakers the volume necessary to have the low frequency match the high frequency components becomes excessive. In these cases, a practical alternative solution may be to reduce the area of the horn. This reduces the low frequency output and the speaker excursion. The low frequency components can then be boosted electrically. Since the speaker excursion for a given sound output depends on the mouth to throat area ratio of the horn, there will still be a reduction in the inherent distortion.

Figure 3 shows the mechanical impedance (force-current analogue) of the throat of a horn with and without acoustical termination as a function of frequency. Curve 28 is that of an unterminated horn and dashed line curve 29 is that of a horn terminated in accordance with this invention. The points of high impedance correspond to frequencies at which the speaker excursion is high for a given sound output. For example, impedance measurements of this sort can be obtained by constructing a bridge circuit that balances out the electrical impedance of the electro-mechanical transducer associated with the acoustical diaphragm so that only the mechanical impedance is measured.

The resulting frequency response is shown in Figure 4 wherein curve 30 is representative of the frequency response of a terminated horn and dashed line curve 31 of an enclosure such as that illustrated in Figures 1 and 2 without the termination. It is apparent from this curve that the terminating acoustic loading in the horn results in a considerably flatter frequency response than that obtainable with the horn alone.

Curves illustrative of typical measurements of harmonic distortion appear in Figure 5 wherein dashed line curve 32 illustrates the observed distortion in an unterminated enclosure and curve 33 the observed distortion in an acoustically loaded enclosure which has been loaded in accordance with the practice of this invention. It is noted that the non-uniform frequency response for an unloaded horn is particularly critical in that the frequency response of the system is different at the frequencies of the harmonics than it is at the fundamental frequency.

As a specific example of the practice of this invention a combination acoustical horn and loud speaker assembly in the form of that illustrated in Figures 1 and 2 may consist of an 8" loud speaker mounted in baffle member 18. The flare of the horn is approximately exponential. It is noted that a conical or hyperbolic flare may be utilized without departing from the spirit of this invention. If a hyperbolic flare is utilized it is possible to optimize the reactive components of the horn. The termination consists of approximately 5 pounds of fiber padding such as that normally used for packing glass ware. Burlap, rags or other sound absorbing material may be used with equal success. The proper amount of padding and its placement can be determined by impedance and/or frequency response measurements since if the loading is not correct, the impedance characteristics will fluctuate. The entire assembly is approximately 40 inches high with a sound radiating face area of approximately 1.5 square feet.

This acoustical horn and speaker assembly provides a sound reproduction down to a low frequency cutoff of the order of 40 cycles per second. It is noted that a conventional labyrinth speaker and horn assembly could not give this response. A conventional non-loaded horn and speaker assembly incorporating an 8 inch speaker would normally have a volume of about 30 cubic feet for reasonably flat response and faithful frequency reproduction. That is, the sound radiating face of such a conventional unterminated horn speaker would have a sound radiating face area of approximately 16 square feet while a corresponding speaker and cabinet assembly such as that illustrated in Figures 1 and 2 has a

volume of about 3.2 cubic feet with a sound radiating face area of approximately 1.5 square feet.

It is noted that the horn assembly can be constructed out of any satisfactory material such as pressed board, plywood or plastic. The given dimensions are considered to be exemplary only, since the practice of this invention can be carried out with any number of acoustical diaphragm and horn assemblies depending on the particular frequency response requirements and the available space.

Referring to Figure 6 of the drawing, which is a perspective view of an alternative structure according to this invention, the assembly comprises a cabinet 34 having a sound radiating face 35 across which a grill cloth 36 is normally positioned. Supported within the cabinet 34 is an electro-acoustic transducer unit 37 including a cone diaphragm 38 which occupies a portion of the sound-radiating face 35 in a position to direct sound outward from the cabinet. A series of baffles 39 on the interior of the cabinet 34 define an approximately exponentially expanding passageway positioned to direct sound waves from the back of cone diaphragm 38 through the portion of the sound radiating face 35 not occupied by the cone diaphragm 38.

The mouth of the exponential horn defined by the baffles 39 has a terminating diaphragm 40 of soft padding material positioned across it. The material of the diaphragm 40 must be partially sound-absorbing and partially sound-transmitting. For example, loosely felted wool or cotton fibers are satisfactory for this purpose as are a number of thicknesses of wide mesh woven fabrics.

The presence of the terminating diaphragm 40 allows the cabinet 34 to be smaller than would be the case for an unterminated horn for the same low frequency cutoff. The mass of the terminating diaphragm 40 replaces the mass of air in the mouth of an equivalent longer horn. Since the mouth end occupies the largest volume, this results in a volume saving as great as 50 percent. In addition, an impedance matching layer or stuffing of sound absorbent material 41 is provided as an aid in obtaining the desired impedance match and frequency response.

While this invention has been described in connection with specific exemplary embodiments it is apparent that it is subject to numerous modifications and it is intended in the appended claims to cover all modifications and variations that come within the true spirit and scope thereof.

What I intend to claim by Letters Patent of the United States is:

1. An acoustic horn assembly comprising a cabinet having a sound-radiating face, an acoustic diaphragm mounted in said cabinet with the exterior side of said acoustic diaphragm coupled to a portion of said sound radiating face, at least one baffle in said cabinet providing a horn for directing sound waves from the interior side of said acoustic diaphragm to a portion of said sound-radiating face, and sound absorbing material positioned in said horn providing a desired frequency response and effectively terminating the horn with an impedance approximately equal to the characteristic impedance of the mouth of said horn.

2. An acoustic horn assembly comprising a cabinet having a sound radiating face, an acoustic diaphragm mounted in said cabinet and having an exterior side coupled to said sound radiating face, at least one baffle in said cabinet providing a horn for directing the low frequency sound waves originating from the interior side of said acoustic diaphragm to the sound radiating face and acoustic loading means including soft padding material positioned in the mouth of said horn effectively terminating the horn with an effective acoustical impedance approximately equal to the characteristic impedance of the mouth of said horn whereby reflections from the mouth of the horn are minimized.

3. An acoustic horn assembly comprising a cabinet having a sound radiating face, an acoustic diaphragm mounted in said cabinet with the exterior side of said acoustic diaphragm coupled to a portion of said sound radiating face, at least one baffle in said cabinet providing a horn for directing sound waves originating from the interior side of said acoustic diaphragm to said portion of said sound radiating face coupled to the exterior side of said acoustic diaphragm, and acoustic impedance means including soft padding material positioned in said horn to effectively terminate the horn with acoustical impedance approximately equal to the characteristic impedance of the mouth of said horn whereby reflections from the mouth of said horn are minimized.

4. An acoustic horn assembly comprising a cabinet having a sound radiating face, an electro-acoustic transducer unit including an acoustic diaphragm mounted in said cabinet with the exterior side of said acoustic diaphragm coupled to a portion of said sound radiating face, at least one baffle in said cabinet providing a horn for directing sound waves originating from the interior side of said acoustic diaphragm to a portion of said sound radiating face not coupled to the exterior side of said acoustic diaphragm, and a diaphragm positioned in the mouth of said horn, said diaphragm having an acoustical impedance approximately equal to the characteristic impedance of the mouth of said horn.

5. An acoustic horn assembly of the type defined by claim 4 wherein said diaphragm positioned in the mouth of said horn includes sound absorbing material.

6. An acoustic horn assembly comprising a cabinet having a sound radiating face, a cone type speaker diaphragm mounted in said cabinet, the exterior sound radiating surface of said cone being coupled to a portion of said sound radiating face, said cabinet providing a horn passageway extending from the interior side of said

cone and having its mouth substantially flush with the portion of said sound radiating face not occupied by said diaphragm and a terminating diaphragm including sound absorbing material in the mouth of said horn, said diaphragm having an effective acoustic impedance approximately equal to the characteristic impedance of the mouth of said horn.

7. An acoustical diaphragm and horn assembly comprising an acoustical diaphragm oriented to radiate high frequency components from the front face thereof, a tapered acoustical horn having a throat portion coupled to the back face of said acoustical diaphragm and a mouth portion oriented in proximity to the front face of said acoustical diaphragm and acoustical loading means inserted in said horn to provide an effective acoustical impedance substantially equal to the characteristic impedance of the mouth of said horn, said horn being dimensioned and loaded so that the high frequency components are substantially attenuated to provide a substantially flat frequency response with a sharp cutoff so that interference between radiation from the front and back faces of the diaphragm is minimized.

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