This invention relates to contracted horns having minimum reflection of sound at the mouth of the horn and some wall leakage.

In the accompanying drawings FIG. 1 represents a longitudinal section of the device constructed in accordance with my invention and FIG. 2 is a graph showing the output pressure response for a horn embodying the invention.

The embodiment of this invention shown in the drawings will now be described in detail.

The horn 1 of FIG. 1 has innumerable pores or slits in the wall 2, which pores are arranged near the mouth portion as described hereinafter. Air is allowed to leak through the pores or slits and is damped by acoustical resistance 3 such as silk cloth or wire gauze stretched over the pores or slits.

The sound wave travelling from the horn throat 4 is initially a plane wave 5 and gradually changes to a spherical wave 6 as it passes the region where the wall has pores or slits. The change in shape of the sound wave results from the fact that the horn tends to have the characteristic of the open end of an acoustical tube at the portion of the horn having pores owing to the leakage through the wall and the wave at the open end assumes the form of spherical wave as is well known.

Upon reaching the horn mouth 7 the sound wave surface can take the form of a sphere 8 whose radius is almost equal to that of the horn mouth if suitable leakage through the wall is allowed. If the radius of the sound wave at 8 is equal to the radius of the horn mouth 7, the sound wave does not reflect at the horn mouth and the output sound pressure of the horn has no peak nor dip at varying frequencies.

According to the theory explained hereinafter, the necessary mouth radius of the horn to satisfy this condition is just half of that of the usual horn. As is well known, the usual horn with a small mouth radius has a bad frequency characteristic owing to the reflection of the sound wave at the horn mouth which is caused by the difference between the radius of the spherical sound wave at the mouth of the horn and the radius of the horn mouth itself.

On the other hand, if leakage through the mouth portion of the wall of the horn is selected in accordance with this invention, horns or apparatus with relatively small mouths, but with excellent frequency characteristics can be made. The tweeter and squawker horns embodying this invention have wider directional characteristics owing to the relatively smaller horn mouths as compared with conventional ones; while woofer horns embodying this invention have more convenient dimensions and weights for domestic use. For example, the usual woofer horns must have mouth dimension of 2 m. x 2 m. in order to truly reproduce bass tones of 50 cycles per second and to maintain an even frequency characteristic.

Further, the so-called horn baffle is also reduced in size for a horn embodying this invention.

The theory of this invention will now be explained briefly with reference to an exponential horn as follows:

Differentiating by time the condensation of the air contained in the increment of volume 9 at the section 11 having a cross-sectional area S and thickness Δx in FIG. 1, and multiplying by ρc^2 we get the sound pressure p:

\[ \frac{\partial p}{\partial t} = \rho \frac{c^2}{2} \frac{S - (u + Δu)(S + ΔS) - gp(2πRΔS)}{SΔx} \]

where

- \( p \) = mean density of air,
- \( c \) = sound velocity,
- \( R \) = radius of the horn at the section 11,
- \( S \) = cross-sectional area of the horn at the section 11,
- \( S_e \) = cross-sectional area at the throat of the horn, e = base of natural logarithms,
- \( x \) = axial distance from the throat to the section 11,
- \( m \) = flaring constant of the horn,
- \( Δa = length of the arc 10 = Δx \sqrt{1 + ((mR/2)^2 \}
- \( (2πRΔS) \) = area of the circular band 10,
- \( u \) = particle velocity of air at the section 11, and
- \( gp \) = particle velocity of air leaking through the pores or slits of the wall.

Now velocity potential φ gives sound pressure \( p = \rho \phi / \partial t \) and particle velocity \( u = \phi / \partial x \) as usual; then Formula 1 leads to equations:

\[ \frac{\partial^2 \phi}{\partial x^2} + m \frac{\partial \phi}{\partial x} + (b^2 - jωG)φ = 0 \]

\[ G = 2πpR/(1 + (mR/2)^2 \]

where \( k = \omega/c \), \( ω \) = angular frequency of sound and \( jω = \sqrt{-1}. \)

The solution \( φ = e^{(b+κ)π} \) of the Equation 2, when \( G \) = constant, is

\[ \lambda = -\sqrt{\frac{m}{2} + bk} \sqrt{1 - b^2 - j(\omega G)} \]

where \( b = \omega c / \omega \) and \( c = m c / 2 \) = cutoff angular frequency of the horn.

In the case of the usual tone range (ω > ωc), \( 1 - b^2 > 0 \); therefore, the argument that is, the angle between a vector and its reference axis, for the function in the root in (4) is negative and acute; then the argument of the root itself is also negative and acute; hence we can put

\[ \lambda = -\sqrt{\frac{m}{2} + bk(a - bj)} \]

where

\[ \sqrt{2a} = \sqrt{(1 - b^2)^2 + (2G/ω)^2} + \sqrt{(1 - b^2)^2 - (2G/ω)^2} > 0 \]

\[ \sqrt{2b} = \sqrt{(1 - b^2)^2 + (2G/ω)^2} - \sqrt{(1 - b^2)^2 - (2G/ω)^2} > 0 \]

The acoustical impedance density of this horn is, then,

\[ Z = \frac{p}{u} = \frac{ρ \phi}{\partial x / (\partial \phi / \partial x)} = ρ jωφ / (-λφ) = ρ C[(a - j(b + β))] \]

The output sound wave at the horn mouth is nearly a spherical wave, the radius of which is almost equal to the
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radius of the horn mouth; and the impedance density at
the mouth is, therefore, nearly equal to

\[ Z_s = \frac{\rho c}{(1 - j/kr)} \]  

(8)

where \( r \) = radius of horn mouth; this computation is well
known in the acoustical engineering of usual or conven-
tional horns.

The condition for avoiding reflection of the sound wave
at the horn mouth is, then,

\[ Z = Z_s \]

or

\[ a - j(b + \beta) = 1 - j/kr \]

\( a = 1 \)

and

\[ b + \beta = 1/kr \]

referring to Equation 6, then, we can derive the condi-
tional equations

\[ r = 1/m \ldots \text{(mouth radius)} \]

\[ G = m/c \ldots \text{(constant)} \]

hence

\[ \frac{g}{1 - \beta^2} \]

\[ 1 = \frac{\rho c}{\sqrt{1 + (mR/2)^2}} \]

(10)

The usual horn with a solid wall has an impedance
density of \( Z' = \frac{\rho c}{\sqrt{1 - \beta^2}} \), which is well-known and also derivable from the Equation 7 when we substi-
tute \( G = 0 \) in the Equations 6 and 5; \( G = 0 \) means that
there is no leakage in the wall; the minimum reflection at
the horn mouth occurs when \( Z' = Z_s \); thence we get

\[ \beta = 1/kr = 1/[\omega/\sigma] = \frac{c}{\sigma r} \]

hence

\[ r = 2/m \ldots \]

(11)

(mouth radius of the usual horn)

According to Equation 9, the radius of the horn en-
bodying this invention has a size of \( 1/m \), which is just
half the size of the mouth radius of the usual horn. To
obtain a good response from this half-sized horn over
its reproducing frequency range, however, the Equation
10 must be satisfied. In Equation 10 \( g \) means the acous-
tical leakage conductance per unit area of the wall and
it will be seen that change in \( g \) along the horn is almost
proportional to the change in \( R \) (the radius of the cross
section of the horn); hence the area of the wall made up

of the pores or slits is to be nearly proportional to \( R \).

It is desirable that the horn wall have no leakage near
its throat, but getting near the mouth, the wall gradu-
ally permits sound leakage in accordance with Equation 10,
and the leakage conductance must be almost real, that is,
purely frictional, rather than inertial or elastic conduct-
ance, in order to obtain the desired condition over the
reproducing frequency range.

One of the invented horns speaks, the response of
which is observed by a Brüel & Kjær's apparatus and is
shown in FIG. 2, has a mouth area of about 230 cm.² and
approximate low and high cutoff frequencies of 320 c./s.
and 3000 c./s. respectively. Its response, which rises 6
dB per octave in the lower range owing to the small size
of the mouth but has no conspicuous peak nor dip, can
easily be compensated by a conventional tone control-
ling device.

This invention is also applicable to all other shapes of
horns such as conical or hyperbolic horns as well as to
the exponential horn of the particular example.

What I claim is:

A contracted horn including a wall flaring from a
throat to a mouth with a flaring constant \( m \), the radius
of the horn at said mouth being equal to approximately
\( 1/m \), the portion of said wall of the horn adjacent
said mouth having openings therein, and acoustical resis-
tance material covering said openings to provide a varying
damped leakage conductance therein of approximately

\[ \frac{1}{\rho c \sqrt{1 + (mR/2)^2}} \]

per unit area at any point along said portion of the wall,
in which \( \rho \) is the mean density of air, \( c \) is the velocity
of sound and \( R \) is the cross-sectional radius of the horn
at said point, thereby to ensure minimum mouth reflection.

![References Cited by the Examiner](https://example.com/References_Cited)

**UNITED STATES PATENTS**

- 1,840,992 1/32 Weltling
- 2,621,261 12/52 Karlsson et al.

**FOREIGN PATENTS**

- 844,769 5/39 France
- 660,150 7/34 Germany
- 22,965 9/38 Great Britain
- 491,510 9/39 Great Britain

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