Acoustical horns and waveguides

Jean-Michel Le Cléac’h
Horns

**etymology:** Greek: καρνον, Latin: cornu.

the *horn* of an animal

a "wind instrument"
(Originally made from animal horns)

Reference to car horns is first recorded in 1901.

Neolithic carving
Laussel cave, France
Pavillon de l’oreille, pavillon acoustique (in French)

Etymology of the french name « pavillon »:

Pavillon de l’oreille = part of the external ear which looks like a butterfly (butterfly = « papillio » in latin, « papillon » in french)

An automatic translation may also lead to surprising results like "small house" or "flag"...
a horn is a tube whose cross-section increases from throat to mouth in order to increase the overall efficiency of the driving element = the diaphragm. The horn itself is a passive component and does not amplify the sound from the driving element as such, but rather improves the coupling efficiency between the speaker driver and the air. The horn can be thought of as an "acoustic transformer" that provides impedance matching between the relatively dense diaphragm material and the air which has a very low density.

This is important because the difference in densities and motional characteristics of the air and of the driving element is a mismatch. The part of the horn next to the speaker cone "driver" is called the "throat" and the large part farthest away from the speaker cone is called the "mouth".
Historical milestones

1876 ____________ Bell’s Telephone

1877 ____________ Edison’s Phonograph

1906 ____________ Lee de Forest’s triode

1920 ____________ first commercial radio broadcast

1920 ____________ first commercial electrical recording

1926 ____________ First commercial talking movie

1953 ____________ Transistor commercialization
The First Horns

Like the simple wooden flute, the bull’s horn has been with us for a very long time. We know from ancient accounts that the horn was used to communicate over long distances, but how far a distance? In the aeons before the sort of background noise pollution we have all become accustomed to, the sound of a horn could be heard for miles. As well, sound carries over water—so well, in fact, that on a calm evening, while on the water, normal conversation may carry up to half a mile. And the reflective properties of hillsides and mountains can sometimes carry the sound of a horn a good ten miles and more!

How was a bull’s horn used in hunting? There were two ways. No one is certain which of these characteristics came first but the bull’s horn was used by hunters to pass on needed information in the conducting of the hunt. As well...
Carved Conque Shell from Nepal with the Goddess Kharaccheri in a Mandala.
megaphones

Fisherman using a megaphone

Echo Lake megaphone

Giant megaphone in Brussels

And now she beats her heart, whereat it groans,
That all the neighbour caves, as seeming troubled,
Make verbal repetition of her moans;
Passion on passion deeply is redoubled:
‘Ay me,’ she cries, and twenty times, ‘Woe, woe’,
And twenty echoes twenty times cry so.

« Venus and Adonis », Shakespeare
horns as music instruments

• First horns
  – China
  – Oxus
  – Egypt
  – Greece

• Alphorns and thibetan horns
• Brass instruments
• Strings instruments with horns
First trumpets:
- 4000 BC in China
- 3000 BC in Oxus (Afghanistan-Russia frontier)
- 1500 BC in Egypt
- 300 BC in Greece
- 300 BC in America

Oxus civilization
ancient Greece

greek salpinx

Tutankhamun's trumpets

"tuuut.....!"

ancient Egypt
One of the oldest musical instruments still in use today is the Alphorn,

**Alphorn**

The Alphorn is one of the largest trumpets. It is used in many high mountain regions, particularly in Switzerland. The alphorn is usually made out of mountain trees such as young firs, lime trees, or poplars. They are split in half and hollowed out. The halves are rejoined and bound with bark strips, rattan, or gut.

Cowherds use the alphorn to signal to each other across alpine pastures. It has also been used to summon communities to church, or to war.
Brass instruments from the 19th
The World’s Largest Saxophone

There is plenty of music in this horn. Standing six feet, seven inches in height, this saxophone is believed to be the largest in the world. In spite of its height it may be played from a sitting position—provided the musician is sufficiently expert.

A tripod support is needed for this saxophone.

BRASS HORN TWELVE FEET LONG PLAYED BY SIX MIDGETS

Measuring 12 feet in length, a giant horn requires at least two men to play it, as it is so cumbersome that one person cannot carry it. Recently, at a convention in the South, six midget men were necessary to handle the instrument: one at the mouth-piece, another at the keys, and four to support it. This huge band piece was made in Paris and brought to this country about 75 years ago.

Massive Brass Instrument that Is Played by Two Midgets while Four Others Hold It

A brass horn used to load a loudspeaker by Susumu Sakuma

Vuvuzela: Should the horn be banned from the World Cup?

June 16, 2010 11:19 AM
By PO

It's the horn heard around the world, broadcast into living rooms and bars as people tune into the 2010 FIFA World Cup. The vuvuzela, a stadium horn popular with South African soccer fans, has become the symbol of this year's tournament, but not everyone is enjoying the festive instrument's loud sounds.

Some fans have called the noise annoying, especially while watching games, and those closer to the action are concerned about potential hearing damage.

World Cup organizers are even considering a ban on the 127-decibel horn.

What do you think of the vuvuzela? Should it be banned from World Cup matches?

Should the vuvuzela be banned from World Cup games?

☐ Yes
☐ No
Vote/See Results
Share ThisPolldaily.com

127dB!

vuvuzela
When strings meet horns
Non musical purposes

- architectural acoustics
- foghorns
- firemen sirens
- car horns and Klaxon
- military megaphones
- acoustic locators
Architectural purposes

Horns used in ancient architecture

The prince listening to the courtiers speaking outside the building

Athanasius Kircher invented the megaphone
(1608 Germany - 1680 Italy)

Today in Mexico
foghorns

Tyndall’s fog-horn

Circa 1873

Tyndall’s fog-horn

foghorns designed by Lord Rayleigh
Trevose Head Lighthouse, Cornwall (1913)
Edison Uses Klaxons to Warn Men of Fire

Kopenhagen siren

Firemen siren

Train horns

sirens and klaxons

Klaxons

a siren playing trumpet

victim of pollution
military megaphones

Bugle Call into Megaphone Gets 'em Up in the Morning

Reveille sounds painfully loud these days to the boys in camp at Fort Jackson, S. C. When the bugler sounds “I can’t get 'em up in the morning” he steps to a huge megaphone that blasts his notes throughout the camp. Mess call, he finds, does not require so much artificial amplification.

The bugler at Fort Jackson, S. C., (left) covers plenty of ground with the help of a big megaphone suspended in a frame at his post.
before radar:

acoustic locators
‘What, canst thou talk?’ quoth she, ‘hast thou a tongue? O would thou hadst not, or I had no hearing. Thy mermaid’s voice hath done me double wrong; I had my load before, now pressed with bearing; Melodious discord, heavenly tune harsh sounding, Ears deep sweet music, and heart’s deep sore wounding.

Shakespeare
Recording and reproducing sounds

The very first recording of sound was made by Edouard Léon Scott de Martinville with his « phonautographe » before 1857, probably 1854 as written in his writing « Fixation graphique de la voix (1857) ». He didn’t know how to reproduce those sounds.

First successful recording followed by its reproducing (1877) is due to Thomas Alva Edison with his « phonograph ».
Phonautograph

2 phonautograms

a simplistic horn
In December of 1877, Edison’s machinist presented him with the completed prototype. Edison leaned toward the recording horn and shouted out the words “Mary had a little lamb, its fleece was white as snow, and everywhere that Mary went, the lamb was sure to go.” It was hardly a moving speech, but then nobody—not even Edison—expected the machine to work the first time. To his great surprise, a highly distorted but recognizable version of Edison’s words spilled out of the machine when the tinfoil was cranked under the needle once again.
At the French Academy

Phonograph Victor V, (1907)

Recording of a piano on a cylinder

Edison Thomas.mp3

Recording at Smithsonian

Dickson first Experimental sound film (1894)

For recording through the horn, the head was replaced by a "recording head"
The famous oil painting "His Master's Voice" by Francis Barraud (1893) of the dog Nipper and an Edison-Bell cylinder phonograph, using a horn to load the mechanical transducer to provide the “amplification” necessary to hear the recording.

**Phonograph Carried as Vanity Case**
Plays Standard-Size Records

Carried like a vanity case and about the same size, a collapsible phonograph that plays standard records has been invented.

**Watch-Case Phonograph**

Called the world's tiniest talking machine, a miniature phonograph has been built into the case of a watch. When wound by the watch stem, a small spring mechanism turns a midget record. Sound is reproduced through a diminutive horn.
The E.M.G. Mark Xa gramophone

HORN THEORY AND THE PHONOGRAPH

Percy Wilson

Balmain Gramophone with 5ft. Straight Horn

Trapezoidal Horn Fitted to an "Expert" Gramophone

see: « Horn theory and the gramophone »
Percy Wilson in JAES 1974
Electronic tube time

The world's first commercial electrical recording
The setup for Guest and Merriman's pioneering electrical recording of the Burial of the Unknown Soldier in Westminster Abbey on 11 November 1920.

On February 25, 1925, Art Gillham recorded "You May Be Lonesome", a song written by Art Gillham and Billy Smythe.

It was the first master recorded to be released using Western Electric's electrical recording system.
In Pittsburgh, Westinghouse radio station KDKA schedules the first commercial radio broadcast—the Harding-Cox presidential election results.
a question of conversion efficiency of the energy

A boat at the interface between air and water.

To move the boat it is far more efficient to action the oars inside the water than in the air.

characteristic impedance of air is about 420 Pa s/m
characteristic impedance of water is about 1.5 MPa s/m
(nearly 3600 times higher)
the purpose of horns

- to progressively adapt the acoustical impedance from the throat to the mouth

- to control the dispersion of the waves outgoing from the horn
The specific acoustic impedance $z$ of an acoustic component (in N·s/m³) is the ratio of sound pressure $p$ to particle velocity $v$ at its connection point:

$$z = \frac{p}{v} = \frac{I}{v^2} = \frac{p^2}{I}$$

**Where:**

- $p$ is the **sound pressure** (N/m² or Pa),
- $v$ is the **particle velocity** (m/s),
- $I$ is the **sound intensity** (W/m²)
Sound power:
if no loss inside the horn:

\[ P_m = P_t \]

Sound intensity:
it is the sound power per unit area

\[ I_t = \frac{P_t}{A_t} \]
\[ I_m = \frac{P_m}{A_m} \]

Thus:

\[ \frac{I_t}{I_m} = \frac{A_m}{A_t} \]

For a given sound intensity the intensity at throat will be proportionnal to the ratio of the mouth area on the throat area
acoustical impedance adaptation
the horn creates a higher acoustic impedance for the transducer to work into, thus allowing more power to be transferred to the air.
- increase of efficiency (up to 50%)
  use of low power amplifiers
  lower distortion due to smaller displacement of the membrane

- acoustical gain (10dB and more)

control of the dispersion of the sound waves
- depends on the need of a narrow or a wide spread of the sound in the room
Webster's equation

Webster's equation for a constant bulk modulus:

\[
\frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} = \frac{\partial^2 p}{\partial x^2} + \frac{1}{S} \frac{dS}{dx} \frac{\partial p}{\partial x}
\]

where:

\[c^2 = B/\rho\]

The only assumption which has been made is that the wave is a function of one parameter.

No further assumption is made about the shape of the isophase surfaces. Plane waves, spherical waves, or other wavefront shapes can be assumed within the framework of Webster's equation.
One parameter hypothesis or 1P hypothesis

1) pressure $p$ depends only on a single coordinate

2) only longitudinal waves propagates from throat to mouth

Theory tells us:
only 3 shapes for the wavefront and for the infinitesimal sound duct obey to the 1P hypothesis:

- wavefront shape: planar, spherical cap, cylinder
- duct shape: cylindrical tube, conical horn, toroidal horn
• isophase surfaces are parallel
• isophase surfaces are perpendicular to horn wall
• isobare (= isopressure) surfaces are parallel to isophase
COMMENTS ON THE THEORY OF HORN

BY WILLIAM M. HALL
Massachusetts Institute of Technology

ABSTRACT

The present theory of horns makes a number of assumptions and approximations relative to the nature of the motion within the horns. This paper discusses these assumptions and presents the results of an experimental investigation of the sound fields within a conical and an exponential horn. These results show the conditions actually existing in these particular cases, and therefore indicate to a certain extent the validity of the above assumptions and approximations.

at the frequencies measured. Change in its location produced no noticeable effect on the output of another transmitter mounted near it, and the general consistency of the results obtained tend to substantiate the measurements.

PLATE I. Relative amplitude and phase of pressure within exponential horn at 120 c.p.s.
Diameter of mouth of horn 72 cm.
Length of horn 173 cm.
Area given by $A = A_0 e^{-kr}$.

PLATE III. Relative amplitude and phase of pressure within conical horn at 600 c.p.s.
Diameter of mouth of horn 76 cm.
Length of horn 183 cm.

The investigation was limited to the case of infinitesimal waves. Therefore no information was obtained relative to the assumptions and approximations of the classical theory of sound as they have been outlined above. However, the investigation did give considerable informa-
For horns for which \( p \) depends on 2 or 3 coordinates we have to take in account high order modes (HOM).

The general solution to the Helmholtz equation in a 2D waveguide can be written

\[
p(x, y) = (A e^{-i\sqrt{\omega^2/c^2 - \zeta^2}x} + B e^{i\sqrt{\omega^2/c^2 - \zeta^2}x})(C e^{-i\xi y} + D e^{i\xi y}),
\]

where \( \zeta = n\pi c/(2a) \), \( n = 0, 1, 2, \ldots \). The cut-off frequency \( f_c \) of a higher order mode is associated with the longitudinal wavenumber becoming imaginary. This occurs at \( \omega_c = n\pi c/(2a) \) or \( f_c = nc/(4a) \). With \( a = 0.05 \) m and \( c = 345 \) m/s, we have \( f_c = 1725 \) Hz for \( n = 1 \). At 850 Hz, the amplitude of the first non-planar mode will decay with a factor of around \( 10^6 \) within a distance of \( \ell = 0.5 \) m. Thus, setting the upper frequency bound to 850 Hz, the higher mode contamination at \( \Gamma_{in} \) can thus be expected to be negligible.
to take in account the fundamental mode only is not sufficient to rely simulation to measurement
The quest for efficiency, the quest for loading

In 1926, the Vitaphone system uses the famous driver WE 555-W coupled to the WE15A horn (100Hz to 5kHz).
Acoustic studies using the WE15A.
See on right Wente's planar waves tube he used to measure the power response of the WE555 driver
development of the Stereophonic system (commercially introduced in 1933)
In 1928 the seven Hollywood majors released 220 silent films and 74 sound films, of which 41 had only synchronized music and sound effects, 23 were part talkie and only 10, all from Warner Bros, were all talkie. Universal and Paramount in particular were still heavily committed to silent productions.

1926 "Don Juan" first talking movie,

In 1929 the balance had shifted radically. By now there were 166 all talkie releases, 50 part talkie and 36 with only music and effects. Silent releases had dwindled to only 38 out of a total of 290.

1927 "The Jazz Singer"
Talking Devices are Revolutionizing Movies!

Talkies Created New Movie Jobs, But Put Many Musicians Out of Work

This map of electrical equipment is used in making sound pictures which have put thousands of musicians out of work, replacing theater orchestras.
Talking Devices are Revolutionizing Movies!

Sid Grauman's Chinese theater in Hollywood inaugurated in 1927
1960s

80 \times \text{JBL375} + 40 \times \text{JBL150H}

600 acoustic watts

Generator for vibration analysis

© Harman International, Courtesy Mark Gander and John Eargle

multiple horns
Related to horns

- acoustic lenses
- diffractor couplers (Karlson coupler)
- reflectors
Klanfilm horn with acoustic lens at mouth

Acoustic lenses

JBL acoustic lens

JBL "potatoe crusher"
THE TUBE...

Product

The Tube is a direct replacement for all H.F. units that operate between 800 Hz and 25000 Hz (depending on the Driver used). The pattern does not vary with frequency unlike horns of even the multicellular and sectoral types.

Karlson coupler
Elliptical reflectors = acoustic shells
Folding horns

• In search of miniaturization
old folded horns
Radio Increases Milk Yield of Cows With Musical Ear

That cows will give more milk to the strains of music was proven when Ben Scott, in charge of the cattle at the Fredmar Farms near Oakville, Mo., installed a radio loudspeaker for the benefit of the restless bovines. They immediately showed signs of musical appreciation and stood still while they were milked. Some even cocked a musical ear while the soothing strains of a classical waltz came from the radio.

As an almost conclusive proof to the new idea, the cow pictured boasts of an official record for 3-year-olds with 840.98 pounds butter and 17,364 of milk.
WE « the Tub », circa 1938

WE collector in Japan
Fletcher system (1933-1940)
modern folded horns

YL folded horns (Japan)

University Cobraflex

Technics folded horns
Yoshimura Laboratory, Ale and Goto horns

Nelson Pass’s fullrange Kleinhorn

Yamamura fullrange Churchill and Dionisio 32
First folded bass horns

The Shearer horn system received a technical achievement award at the 1936 Academy of Motion Picture Arts and Sciences ceremony.
Straight horns
Early exponential straight horns

Before 1929

my home made crystal radio with a Vitavox E190 horn
Horn tweeters
Klangfilm
20 hz Tractrix horn
Germany, 1951
Straight bass horns

Bjorn Kolbrek’s long throw bass horns
Vincent Brient’s 30Hz bass horns (France)

Klaus Speth, full horns with Goto drivers (Germany)
Quasi cylindrical waves bass horns in France

Jean-Paul

Marcel Roggero

Frédéric Lebas

... and this is my listening room

AUDIO • APRIL, 1954
main families of horns

- Salmon family  (exponential, hypex, etc.)
- Tractrix, Kugelwellen and Spherical
- conical
- oblate spheroidal
- Le Cléac'h
$F_c = 500 \text{Hz horns}$

- sinh ($T>1$)
- exponential
- cosh ($T<1$)
- hypex
- catenoidal ($T=0$)

**Hyperbolical family**

Mouth area = 700 cm$^2$

**Tractrix**

+ Kugelwellen

**Spherical**

Le Cléac'h

**Conical and waveguides**

- Conical
- Oblate spheroidal

Same mouth area and length as the exponential horn
hyperbolical type

- from catenoidal \((T = 0)\)
- through hypex \((0,5 < T < 1)\)
- and exponential \((T = 1)\)
- to hyperbolic sine \((T > 1)\)

\[
Z_1 = \frac{R \cos (\beta L + \theta) + j(X \cos (\beta L + \theta) + \sin \beta L)}{-X \sin \beta L + \cos (\beta L - \theta) + jR \sin \beta L}
\]

\[= R^1 + jX^1\]

Formula for the acoustic impedance of an exponential horn
hyperbolic / exponential horns

Area = Throat Area \left[ \cosh \left( x^2 \frac{2 \pi f}{c} \right) + M \cosh \left( x^2 \frac{2 \pi f}{c} \right) \right] \frac{1}{2}

where

- $x$ = distance from throat
- $f$ = the cutoff frequency of the horn
- $M$ = the flare constant - $M = 1$ is exponential, $0 < M < 1$ is hyperbolic
- $c$ = the speed of sound, approximately 13538 inches per second or 344 m/s
  (depends on temperature, etc.)
The equation is given by:

\[ A x = A h \left( \cosh \frac{x}{x_o} + T \sinh \frac{x}{x_o} \right)^2 \]

For \( T \gg 1 \) the profile becomes progressively conical.

Profiles of hyperbolic family horns with \( T \) value variation between 0 and 128.
the Tractrix horn

Paul G.A.H. Voigt
(1902-1981)

the mathematical pseudosphere

a square tractrix horn built by Edison Bell in England

\[ x = r_m \cdot \ln \left( \frac{r_m + \sqrt{r_m^2 - r_x^2}}{r_x} \right) - \sqrt{r_m^2 - r_x^2} \]

- \( x \) is the distance from the mouth
- \( r_m \) is the radius at the full Tractrix mouth \( = c / (2 \times \pi \times f_c) \)
- \( r_x \) is the radius at distance \( x \) from the mouth
"The only way that he could figure out to make his driver sound good was to horn load it, but he couldn't understand the mathematics behind the exponential, so he said, "Well, the exponential theory predicts that the wave form going down the horn is plane or flat, but if you look at the physics of the situation, the wave front has to drag along the horn walls. So naturally it's going to be curved. What if I geometrically designed a horn that has curved wave fronts all the way through the horn and see what happens?"

So he did a geometrical construction of a horn that would give him curved wave fronts. *He said that a draftsman looked at what he had done and said, "Oh, that's a Tractrix curve."* The Tractrix curve comes about because if you have one airplane chasing another on a different course, then the chase plane has to change his course to intercept the other plane, and it turns out that's a Tractrix curve."

*Bruce Edgar on Voigt's tractrix*
The expansion law of the Tractrix horn is given by:

\[ A = 2 \pi R h = 2 \pi R^2 [1 - \cos(\alpha)] \]

where \( A \) is the area, \( R \) is the radius, \( h \) is the height, and \( \alpha \) is the angle of the tractrix.

Graphical representation showing the relationship between the spherical wavefront area and the distance from the mouth. The graph indicates a higher rate of expansion and an exponential expansion as the distance from the mouth increases.
Kugelwellen

*Rösch (KLANGFILM laboratories)*

radius is the double of the radius used in the tractrix horn

Bild 184. Mantellinie des bisher üblichen Exponentialtrichters (*a*) und des Kugelwellenrichters (*b*) mit einem Anfangsradius $r_0 = 0.095d_1$

see also: H. Schmidt: "Über eine neue Lautsprecherkombination" Funk und Ton N°5, 1950, p.226-232
Kugelwellen

Wireline 3D view of a Kugelwellen horn
radiation diagram of the Kugelwellen horn
"Le Cléac'h" horn
Le Cléac’h’s method to calculate the profile of an horn knowing the relation between the area of the wavefront and its distance to throat.

\[ R1, R2, R3 = \text{calculated radius of wavefronts} \]
\[ R4^* = \text{estimated radius} \]
\[
\text{estimated radius } R4^* = 3 \, R3 - 3 \, R2 + R1
\]

\[ \text{area3}^* = \text{estimated wavefront area} \]
\[
\text{area3}^* = \left[ 2 \sqrt{\text{area2}} - \sqrt{\text{area1}} \right]^2
\]

area1, area2 and area3 = calculated wavefront areas

area of the outer added element = area3 - area3^*
Wireline 3D view of a Le Cléac’h horn
Le Cléac'h horns (JMLC) that compromise superb pressure linearity, good bass extension, and time domain behavior. Below example with TAD2001

Current driven

Voltage driven

Current driven

Voltage driven

analysis by Jacek Zagaja
J321  (Fc = 320Hz)

directivity pattern of few Le Cléac'h horns

J871  (Fc = 870Hz)
compared profiles of exponential, spherical, Le Cléac’h, Kugelwellen, tractrix, tractrix revisited

Note how the profiles of the Kugelwellen and Le Cléac’h horns are very similar.
waveguides

The benefits of the directivity of a waveguide are improved frequency response and SPL levels within the included angle of the waveguide within the operating frequency band of the waveguide.

In addition, sidewall and floor bounce reflections are reduced by the controlled directivity.
The simple formula for a conical horn is:

\[ S = S_1 x^2 \]

- \( S \) = the area at the horn mouth
- \( S_1 \) = the area at the horn throat
- \( x \) = the length of the horn
"The concept of a waveguide as a direct solution to the wave equation was shown to be capable of exact solution, free of the plane wave assumption of Webster's equation."

\[ S = Ax^2 + B\sqrt{r^2 - x^2} + C \]
oblate spheroidal system of coordinates
While the summed power response radiated by the OS waveguide in full space is very smooth, the frequency response curve at any given angle from the axis is never smooth.

See measurements of Earl Geddes loudspeaker on page 123.
modelisation
and simulation
of horns
above: the first models used a tank filled of water.

on right: later finite elements methods were used
one of the first publication on FEM results of the simulation of soundfields in horns
Measurements performed by Morse

Finite elements analysis of an exponential horn by John Sheerin

Analysis using Cara performed by Michael Gertsgrasser

« wavetank » analysis in David McBean’s Hornresp » software.
Radiation from a baffled disk at different frequencies

Polar graph with a 3D presentation

Various simulations of the radiation of a piston and of a horn.
conical horn

Note the distortion of the shape of the wavefronts

Le Cléac'h horn

Note the very smooth wavefronts

FEM simulations performed by John Sheerin

*(Half horn represented only)*
simulations of an OS waveguide at different frequencies

*Note the wavy isobare curves over 2000Hz*
Note the smoothness and the linarity of the isolevel contours.

polars obtained by FEA of a 275Hz tractrix horn and a 275Hz Le Cléac'h horn

FEM simulations performed by John Sheerin
simulation by John Sheerin

Note the smooth response curves off axis

my measurements on the J321 horn

Le Cléac'h horn
backreflected waves, High Order Modes (HOMs) and stored energy
reflected waves from mouth to throat inside a horn.

\[
\begin{align*}
\text{micro} & \quad \text{t1} & \quad \text{t0} \\
& & \quad \text{Single reflection} \\
& & \quad \text{Double reflection} \\
& & \quad \text{Triple reflection} \\
\text{t2} = \text{t1} + \text{t0} \\
\text{t3} = \text{t1} + 3 \text{t0} \\
\text{t4} = \text{t1} + 5 \text{t0}
\end{align*}
\]
When the pathlength between the direct wave and the reflected wave is equal to a multiple of the wavelength at the considered frequency, we observe a summation of their pressure.

When the pathlength between the direct wave and the reflected wave is equal to an odd multiple of the half wavelength at the considered frequency, we observe a subtraction of their pressure.

easy demonstration of back reflected waves with a PC loudspeaker, a magazine forming a cone and a towel
Table 3. Horn loudspeaker samples grouped according to similarity.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Manufacturer/Type</th>
<th>Flare Material</th>
<th>Flare Rate</th>
<th>Length (mm)</th>
<th>Mouth Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vitavox exponential</td>
<td>Aluminum</td>
<td>Medium</td>
<td>340</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>AX1 axisymmetric*</td>
<td>Glass-fiber</td>
<td>Low</td>
<td>230</td>
<td>Small</td>
</tr>
<tr>
<td>5</td>
<td>Reflexion Arts</td>
<td>Glass-fiber</td>
<td>Medium</td>
<td>330</td>
<td>Medium</td>
</tr>
<tr>
<td>7</td>
<td>Reflexion Arts, no lips</td>
<td>Glass-fiber</td>
<td>Medium</td>
<td>240</td>
<td>Medium</td>
</tr>
<tr>
<td>10</td>
<td>Fostex sectoral*</td>
<td>Wood</td>
<td>High</td>
<td>440</td>
<td>Large</td>
</tr>
<tr>
<td>11</td>
<td>JBL axisymmetric</td>
<td>Aluminum</td>
<td>Low</td>
<td>250</td>
<td>Small</td>
</tr>
<tr>
<td>C</td>
<td>Fostex sectoral</td>
<td>Aluminum</td>
<td>Medium</td>
<td>500</td>
<td>Large</td>
</tr>
<tr>
<td>12</td>
<td>Altec sectoral*</td>
<td>Aluminum</td>
<td>Medium</td>
<td>530</td>
<td>Large</td>
</tr>
<tr>
<td>13</td>
<td>Altec multicellular</td>
<td>Aluminum</td>
<td>Low/med</td>
<td>600</td>
<td>Large</td>
</tr>
<tr>
<td>14</td>
<td>Starr gramophone</td>
<td>Wood</td>
<td>Low</td>
<td>650</td>
<td>Medium</td>
</tr>
<tr>
<td>15</td>
<td>Vitavox sectoral</td>
<td>Aluminum</td>
<td>Medium</td>
<td>450</td>
<td>Large</td>
</tr>
<tr>
<td>16</td>
<td>JBL biradial*</td>
<td>Composite</td>
<td>Medium</td>
<td>400</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Sample 8: AX2 horn/Emilar EK175 driver (no. 1). Short axisymmetric horn of glass-fiber construction with a rapid flare rate terminating in a medium-sized mouth. Compression driver as sample 1.

Sample 13: Altec 806C horn/Emilar EK175 driver (no. 1). Large multicellular horn with eight individual flares of sheet aluminum construction joined to a single throat via a cast aluminum manifold. Compression driver as sample 1.

- Horns do sound different from each other, even when fitted with the same driver.
- The two horns having minimal mouth reflections, one long and one short, were not identified as horns and did not sound similar to the direct-radiating reference.
Compared wavelets graphs of 2 horns:

- on left, high reflectance
- on right, very low reflectance

measurements performed at ETF2010
HOMs absorption

Effect of the foam plug

wavelets graph of the oblate spheroidal waveguide

subtraction of the wavelets graph of the OSWGD without its foam plug and with its foam plug

HOMs have non axial travel inside the horn
the wavelets graph may be used in order to show the existence of sub-millisecond delayed energy (HOMs?)
optimization with the goal of a low reflectance
horns having a lower reflectance at mouth have smoother frequency response curves
Shape optimization of an acoustic horn

Erik Bäntsson, Daniel Noreland, and Martin Berggren

May 8, 2002

The initial shape and the splined approximation of the optimal shape from the 27 frequency optimization shown in figure 18.

optimized profile for the lowest reflectance at 27 frequencies

note the increased opening angle at throat
In search of a more constant radiation angle

*The problem of directivity*

- Multicellular horns
- Multisectorial horns
- Constant directivity horns
- Waveguides
  - Quadratic throat waveguide
  - Oblate spheroidal waveguide
multicellular horns

- with curved dividers
- with identical cells

the idea is to split the wavefront near the throat of the horn through several ducts before the wavefront at HF begins to separate from the walls of the horn.
 multicellular horns with curved thin dividers

The dividers follow « flow lines ». Different shapes of cell coexist. Flat mouth

WE 24A, 1936 - 1967
multicellular horns with identical cells

Onken 255 wood and Onken 455 wood horns on top of an Onken W bass reflex enclosure
detail of the assembly of cells
sectorial horns

• sectorial horns have linear (« conical ») expansion in one plane and exponential expansion in the other.

• Dividers can be flat (e.g. Altec 511 and 811) or not (e.g. JBL Smith horn JBL2397)
Smith horn and related

The TAD TH4001 horn has a Smith horn design at throat.

Yuichi Arai’s A300 horn
Altec

diffraction zones in red

the Mantaray horn
from diffraction horns to biradial horns

Electro Voice

Directivity control

its goal:

to obtain a more constant frequency response over a chosen solid angle
Oblate spheroidal waveguide

Note the rather constant directivity over 1kHz and the wavy contours

horn calculated by the "Le Cléac'h" method

Note the directivity regularly increasing with frequency and the smooth contours

*simulations using Hornresp*
Earl Geddes’s « Summa Cum Laudae »
2 ways enclosure

See also:

Acoustic waveguide for controlled sound radiation
United States Patent 7068805

Earl Geddes
only modes 00, 0i, j0 exist with round horns
each High Order Mode has its own cut-off frequency
Michael Gerstgrasser's min phase horn is a good compromise between the Le Cléac'h horn and the OS Waveguide.
from 1 to 4 the profile of the mouth of an OS waveguide is curved at a nearer distance from the throat

simulations performed by Michael Gerstgrasser using AxiDriver

from 1 to 4, note the more evenly distributed pressure field
The Min-Phase horn provides a better directivity control than the Le Cléac'h horn while keeping the smoothness of the frequency response curves on and off axis.
the END

a new Le Cléac'h horn (2007)

horns commercialized by Pathé (France), 1903