A New Full Range Horn of Small Dimensions

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The technology of loudspeakers has evolved considerably since some of the early pioneers of the 1930's, yet the *art* remains the same. It is the belief of this author that enough mystery remains in the science of high fidelity to prohibit us from achieving certain levels of success without first achieving an open mind. Those who seek a balance between science and creativity are certainly more likely to succeed. It is this higher form of intelligent engineering that brings us a new form of loudspeaker horn unlike anything previously documented by anyone to my knowledge.

It is also this authors belief that should the recipients of any invention know of the designers actual intentions, they would certainly be in a better position to judge its success or failures accurately. In that light it should be said that this author has been successfully designing both audiophile grade loudspeakers and special application loudspeakers for 15 years, taking that opportunity to indulge in all common design theories and experience the results vs. accepting other's sometimes misguided or miss quoted documentation.

The actual event which motivated this new loudspeaker horn came when this author sat 8 feet in front of a drum set in an associates recording studio during a session. "At that time with the kick of that drum skin driving right through my body, I quietly realized that no pair of home loudspeakers exist that can replicate that experience as if it were real. It was on the way home that I defined the parameters by which I would proceed:

***It has to be small enough to fit in an average listening room and be esthetically pleasing. (reference room LAKE)**

***It must be efficient enough to create the experience with obtainable amplifiers of approximately 200 watts Class A/B or less.**

***It must recreate the experience which motivated it's creation.**

A new loudspeaker horn is described. It is a WIDE BAND frequency horn so folded as to utilize wall and floor reflections to improve the impedance match at the mouth. When operated in a room corner, the loudspeaker is capable of reproducing sounds of wavelengths over eight times the actual apparatus dimensions with an efficiency and smoothness of response comparable to theater "woofers" of several times the size of the device described. Since it's size (footprint) is only 24 x 24 inches and aprox. 4 feet in height it is applicable to living-room use. Because of its high efficiency, its use for small theaters and recreation centers is indicated.

With the original multi-unit drive pack it is capable of delivering the large amounts of power required for large theaters. Units may by stacked or clustered for outdoor use. With a frequency range of 35 to 7500 cycles it is capable of high fidelity when used with a suitable high-frequency unit of which one has been specially designed in conjunction with this horn. Since the H.F. unit needs to deliver power only down to a low of 4500 Hz, it may be made quite small.

The loading due to the horn offers a high real component of impedance for the diaphragm to work against, resulting in low diaphragm excursion and consequently the generation of negligible harmonic components compared with what would be generated by the same driving unit delivering the same sound output from a flat baffle or bass reflex enclosure.

Motional impedance measurements show that the efficiency is good down to between 35 and 45 cycles. The use of the corner, which is ordinarily wasted space, and the arrangement of the side baffles so that they, together with the room walls, form the terminal section of the horn, results in a simple compact structure and a considerable saving in material. In spite of the small size there is no sacrifice in quality.

INTRODUCTION

Many schemes for utilizing the higher acoustical impedance existing in a room corner have been devised. Kellogg, Stone, Weil, Ephraim, Sandeman, and Horace-Hulme are representatives of the early art that began in the 1930's. Since that time, companies like Jenson International, Altec, JBL, Klipsch, and dozens of smaller specialty loudspeaker companies have announced low frequency horn type enclosures in one form or another.

Klipsch was responsible for what this author considers a mutually accepted stereotype of a classic corner horn, with apparently the highest name recognition associated with it. The Klipsch Corner Horn arrived in the mid 1940's, and is still currently being manufactured as of the date of this paper, therefore the author feels it reasonable to assume that in the category of *corner horns* it is the design to challenge.

This text will make direct comparisons with the KLIPSCHORN<tm> because it is being used as a starting point reference for the development and design theories of our new *audiophile* corner horn.

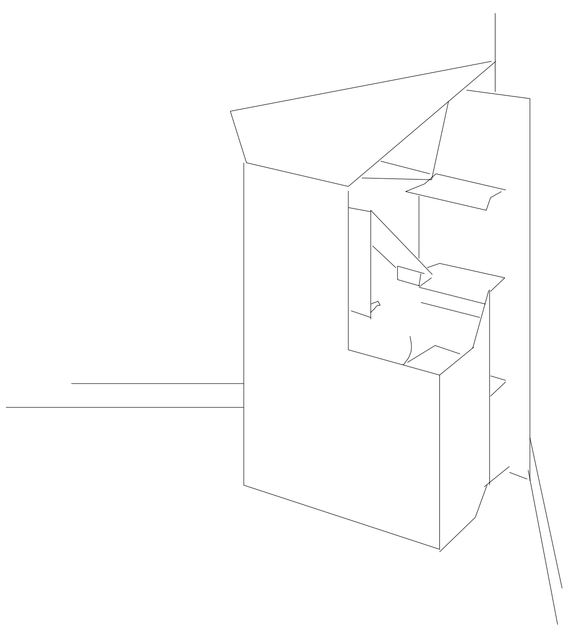


Fig. 1.

The advantages of the horn are well known. Compared to the direct radiator operating in a flat baffle, the efficiency of the horn is 10 to 50 times higher, and the acoustic loading due to the horn permits a greater sound power to be generated with much smaller diaphragm excursions, a factor that greatly reduces harmonic distortion.

Well designed horns are capable of very uniform frequency response. The power-handling capacity is high. A typical theater woofer occupies a space nearly 4x4x8 ft., too big for an average guys living room, making the Klipsch Horn a readily accepted product.

Fig. 1 shows the popular Klipsch Horn, a low frequency horn unit adapted to fit in a corner. Fig. 2 shows our new design, of which I haven't decided what to name it yet but never the less our interpretation of taking a horn design to the extremes of high fidelity. Both horns will mathematically achieve a frequency response down to 40 Hz, corresponding to a wave length of 340 inches (28.3 feet), comparable to the performance of the typical theater woofers . Both horns measure under 4 feet high and less than 32 inches deep from the front panel back to the corner. Their size is entirely suitable for use in homes. The power handling capacity of each is such as to make them adaptable for use in community centers, little theaters, and medium-size clubs.

The Klipsch unit, by suitable modification, can obtain power handling capacity for large theaters. Our unit is designed for both applications by running with the internal driver pack consisting of 4 high speed drivers for commercial use, or by removing them and installing the alternate front baffle, a single 6.5" driver is used for home listening rooms.

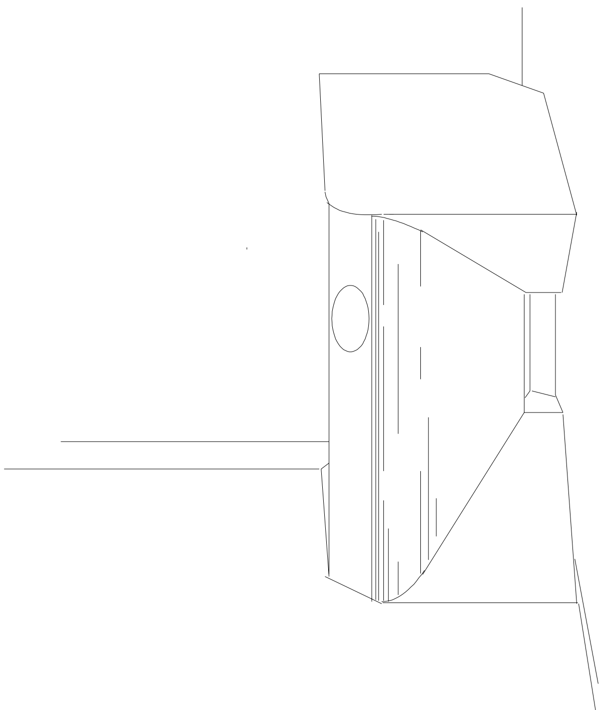


Fig. 2.

Notice in Fig. 2 that our new horn is drawn to the same scale as the horn in Fig. 1 to demonstrate an appreciable reduction in bulk. Also from studying both illustrations you can notice that the unit in Fig. 2 is fully exponential in both the vertical and horizontal planes. The unit in Fig. 1 is not exponential in the vertical plane.

To reproduce a 40 cycle wavelength with the same degree of smoothness of throat impedance and the same efficiency, a conventional horn in free space would require a mouth area of about 4500 square inches. If operated close to a floor or wall, 2300 square inches would be required, corresponding to a circular mouth 53 inches in diameter. The horn length required to match a 15 inch diaphragm would be over 80 inches. The horn in Fig. 1 has an actual mouth opening of 570 square inches and a horn length of approximately 40 inches, representing a saving in volume of over 75 percent and a corresponding saving in material for its construction. A further saving in material results from using the room walls for part of the horn structure. The horn in Fig. 2 has an actual mouth opening of 2016 inches and a length of closer to 50 inches.

RATE OF FLARE

Both horns have a similar area at the throat, the horn in Fig. 3 is aprox. 50 inches, the horn in Fig. 4 is aprox. 50 inches. If you take the mouth area and divide by the throat area you have ratio between the two figures that demonstrate the rate of flare giving some idea to the degree of wave front expansion there will be.

M2 /T2 = R
where
M2 = Mouth area in square inches
T2 = Throat area in square inches
R = Ratio to : 1 flare rate

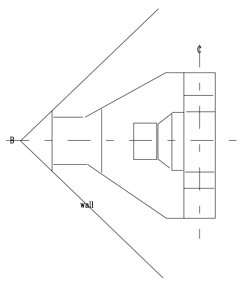


Fig. 3

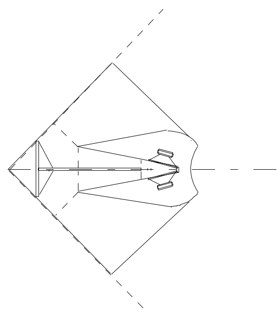


Fig. 4

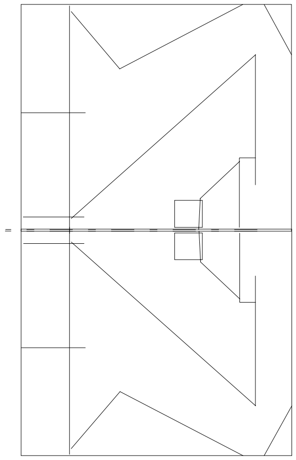
The horn in Fig. 3 has a flare rate of 11.4 to: 1 which will allow for wave front expansion of approximately 1100 percent. The horn in Fig. 4 occupying less physical space has a flare rate of 40.32 to: 1 which will allow for wave front expansion of approximately 4000 percent. As a result we feel we have exceeded the expansion rate at which the wave front grows by 4 times that of the horn in Fig. 3.

DESCRIPTION

Figs. 3 & 4 show the construction of both the Klipsch unit and our unit in matching scale. Fig. 2 is a view showing how the unit is nested into the room corner, and also the arrangement of side baffles, front panel, and driving unit. The side baffles area arranged in such an angle that they, together with the walls, floor, and cover plate, form the final horn section. Radiation into p/2 solid angle (due to the reflections from the walls and floor) make the required mouth area only one fourth as great as would be required for radiation in to 2p solid angle where only the floor is used as a reflector.

Fig. 5 is a vertical section through B-B of Fig. 3 and shows the air passages from the diaphragm to the rear of the horn cabinet. The driving unit and an air chamber behind the diaphragm

Fig. 6 shows the same view of our new horn. The illustration is shown as configured for home use with the 6.5 inch driver located on the front of the baffle towards the top. The two circles shown just below and behind it, are the driver openings for the 5.25" drivers (4 in total) used for commercial applications. When the horn is configured as shown, the 4 openings act as ducts to couple the primary air chamber to the horn throat via a smaller air chamber offering the proper negative reactance to offset the multiple flare of the horn



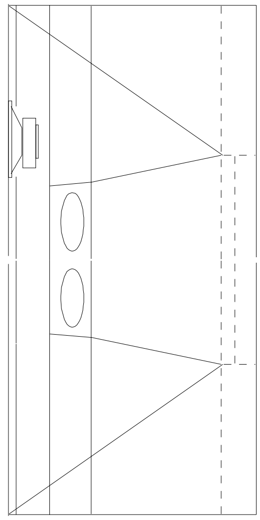


Fig. 5 **Fig. 6**

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When the horn is configured for commercial use the dynamics of how it functions are very different than when configured with the single 6.5" driver, yet the cabinet remains virtually unchanged for both designs, with the exception of changing the front baffle. This obviously makes the value of the product increase, since it is flexible enough to work in both applications without any cabinet alterations.

MULTIPLE FLARE

The Klipsch Horn is a multi-flare design which folds the horn to maximize space without sacrificing performance. In their design, the horn is folded 2 times. However if you count the woofer slapping directly into a parallel surface, as shown in Fig. 5, it is really folded 3 times, which we feel is the limiting factor to the lack of mid frequencies. The response is only good out to 400 cycles before reactance begins to distort the sound.

Fig. 6 illustrates an improvement in the taper design, reducing the number of times the horn is folded to 1 time. Assuming the distance from the throat opening to the first reflective surface in the Klipsch unit is 4 inches it would be impossible to pass a wave cycle above 3000 Hz because the distance between wave fronts would be less than 4 inches, and the surface is parallel to the throat opening. In this situation all frequencies less than 4 inches (above 3KHz) would reflect back into the throat. Besides being unable to pass these higher frequencies, a crossover would be required to filter them off because if allowed to exist, these higher frequencies would create an intense positive reactance, an occurrence which will happen to a degree anyway in the Klipsch multi-flare design. The Klipsch Horn has a usable frequency range from 40 to 400 Hz.

NEW APPROACH TO MULTI-FLARE DESIGN

Our approach to the multi-flare folded horn was to arrange the taper so as to eliminate parallel surfaces, and rather than the first reflective surface being 4 inches away from the driving unit, we moved it 16 inches farther back. This taper will bend frequencies below aprox. 800 cycles, and reflect frequencies above 800 cycles into the listening area. This increased the usable frequency range from 400 Hz in the Klipsch unit, to the natural roll off point of the driving units selected, which in this case is -3db at 4500Hz, and -6db at 9000Hz dropping off rapidly at that point.

If in our horn, the drivers are removed and the unit is re configured for home use, the frequency response of the back wave is introduced to the throat opening via a tuned port which reduces the frequency response of the mouth to around 120 cycles, which are easily bent and presented in a hemispherical wave front from which the 6.5" driver is centered and facing the listening area to pick up frequencies above 120 cycles to the natural roll off point of that driving unit. Either configuration yields the same results in this aspect although the means are extremely different.

In the Klipsch model it is stated that for good diaphragm loading at 400 Hz a throat area of about 50 inches is about right for a 10.5 inch diameter diaphragm and a moving system weighing between 14 and 18 grams. Such a small throat imposes an unnecessarily high load at the lower frequencies. Consequently, the initial taper is such that the horn area doubles in a length of about 8 inches corresponding to a cutoff of 100 Hz. The remainder of the horn flares at such a rate that the area doubles every 16 inches so the nominal cutoff is 47Hz. This results in a "rubber throat" the area of which is about 100 square inches up to 100 Hz and decreases with frequency until at 400 Hz the effective throat area is 50 square inches.

In our horn, the throat area is the same 50 inches, but the initial taper is such that the horn area doubles in a length of about 10 inches. This increased the *mach* speed slightly, and kept the compression higher throughout the first flare. The remaining taper of the horn flares at such a rate that the area doubles approximately every 3 inches.

The illustrations in Fig. 7 give a visual comparison of the two different tapers. The top one is the Klipsch, the bottom one is our new horn.

SINGLE UNDIVIDED FLARE vs. DIVIDED FLARE

If you examine Fig. 3, the top view of the Klipsch model, you will see that from the diaphragm to the terminal end of the horn, that there is no divider. The terminal sections of the horn are indeed separated by a 30" panel, but the separation is lost directly before the last taper. Since the walls of a room corner make up the sides of the last flare *on both Klipsch and Ours*, it is natural to assume that an air tight seal should exist between the walls and the cabinet. Air leaks from uneven walls, or improper placement can result in large peaks usually centered at the frequency division of each flare.

If in a design, as just described, the user was to have gaps on one side from an un-square room corner, the impedance of the horn throat would change, and the reactive action would create a resonance peak affecting both mouth openings. In our design, the horn is devided from the mouth to the throat opening, which will reduce the effects of an improper seal by 25% in the same hypothetical situation. Not a big deal really, but every little thing helps. Designers always assume the individual who purchases their product will set it up perfectly... but this author wouldn't be surprised to find one of his horns situated in the middle of a listening room. It is in fact this very sort of thing that dictated my decision to use the wall corner as part of the horn flare so that people would HAVE to install it directly into the corner.

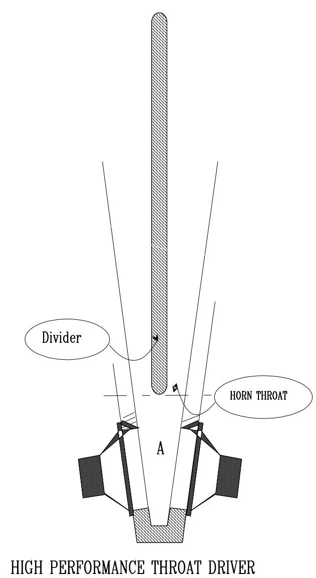


FIG. 8

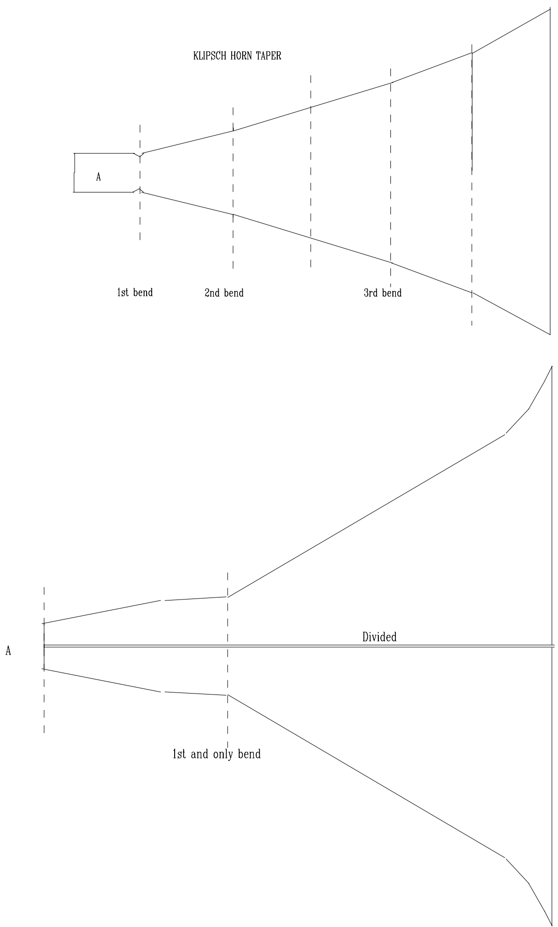


FIG. 7

Mathematical Plot of the horn tapers on each of the two horns.

To overcome the positive reactance imposed at the higher frequencies (200 to 400Hz) by the multiple taper of the KLIPSCHORN, a negative reactance is introduced by the air chamber of about 250 cubic inches between the diaphragm and the throat. This air chamber is shorter than one-eighth wave-length at 400Hz. In our new horn, the air chamber is about 160 cubic inches between the diaphragm and throat, however unlike the KLIPSCHORN, the air chamber is not actually *between* the diaphragm and throat. Since we are using 4, 5-inch diaphragms, and aligned them in a *clamshell* fashion, the air chamber serves to couple the 4 diaphragms together acoustically. This method has been successful in making multiple drivers act and function as one larger driver. See Fig. 8.

Since a 12 inch woofer such as is found in the Klipsch model, is between 14 and 18 grams, with an effective piston diameter of 10.5 inches. Consider that the moving mass of a 12 inch woofer, e piston area of 10.5 inches. The only way to improve its accuracy would be to lower the moving mass. In our model, a driver moving mass is about 9 grams, with a 5 inch effective piston area. The effective piston area of all four drivers is approximately the same as one 12 inch driver. The benefits should be apparent from studying Fig. 8. Each of the four drivers in this configuration are seeing one quarter of the power that the 12 inch would see in the Klipsch model. Assuming power handling capacity of the 5 inch driver is about 1/2 that of a 12 inch driver, we can predict the combination of all four to twice the power capacity as the 12 inch driver. In addition, we can predict that the xmax of each 5 inch driver will be approximately 1/2 to 1/4 as much as the 12 inch driver given the same power single. This translates to:

AIR CHAMBER BETWEEN CONE AND THROAT

* POWER HANDLING has INCREASED
* EFFICIENCY has INCREASED
* TRANSIENT RESPONSE has INCREASED
* MODULATED DISTORTION has been REDUCED

AIR CHAMBER BEHIND CONE

The air chamber behind the diaphragm is designed to offset the mass reactance of the throat impedance at low frequencies.

To offset exactly the throat reactance of an infinite horn, the air chamber behind the diaphragm should have a volume 2.9 times the that area multiplied by the length of the horn within which the area doubles. This is readily shown as follows.

The air chamber reactance, in mechanical ohms, on the diaphragm is
$1/wCm = Ap2\ pc2 / wV.$ (1)

The throat reactance at cutoff, in mechanical ohms, on the diaphragm is
$X\ t = pcAp2/At$ (2)

where

Ap = diaphragm area,
At = throat area,
w = angular velocity at cutoff, = 2p*f*, where *f* is the frequency
V = volume of air chamber
p = density of air
c = velocity of sound.

To make the two reactance's equal, Eqs. (1) and (2) must be equal. Thus,

$V = At\ c / w.$ (3)
The length of the horn within which the area doubles is [*l*]

$l = A / 18.1 = c / 18.1f = 2pc /18.1w$ (4)

where *A* is the longest wavelength to be transmitted, and *f* is the lowest frequency.
Thus,

$V = At\ c(18.1/2pc)\ l = (18.1/2p)At\ l = 2.9At\ l.$ (5)

In the Klipsch design, *l* = 16 inches, and *At* = 100 square inches, so for the infinite horn, *V* = 4600 cubic inches. In a finite horn the throat reactance fluctuates about a value equal to the reactance of a negative capacitance. The initial peak is so large that theory indicated that the air chamber capacitive reactance for the finite horn should be higher than for the infinite horn. Apparently, the reactance can be from 1.5 to 2 times as great for a horn of the length being considered as for the infinite horn.

The diaphragm suspension stiffness contributes some to the total, but in the examples tried with 12 inch speakers this constitutes only 15 to 25 % of the stiffness of the enclosure. In the new design, using 4, 5 inch diaphragms, the figure is significantly less, at between 8 and 12 %. The *clamshell* alignment acts to effectively reduce compliance. In the home version however, we use one 6" driver mounted in the front baffle. In this situation the diaphragm suspension stiffness constitutes about 50% of the stiffness of the enclosure.

Fig. 9 shows our new horn from the front view and the high frequency horn sitting on top.

CONSTRUCTION

This author, being a seasoned carpenter, built the first (and only) prototype model. 3/4 inch high density particle board is used throughout. The curves and compound angles including the 16 degree knife edge of the first bend proved to be quite a test of ones abilities. The cabinet is internally braced, and structurally sound. We estimate the architecture of this cabinet to support a downward force of approximately 7.5 tons when applied to the top of the cabinet in a footprint of one square foot. The cabinet is assembled and glued with a two part resin system yielding superior bonding strength, creating a water proof joint. The cabinets are sealed on all surfaces with a polu/acrylic varnish to protect from humidity and insects. After the proper cure time, the completed horn is then tested with ambient resonant energy across the frequency band, from 35 to around 2800 cycles. This is the process which determined the original bracing topology, based on the results of several test spots using a piazo accelerometer to gain readings. The test will always find dry joints, or assembly problems of any kind. (Not to mention aggravate your neighbors.)

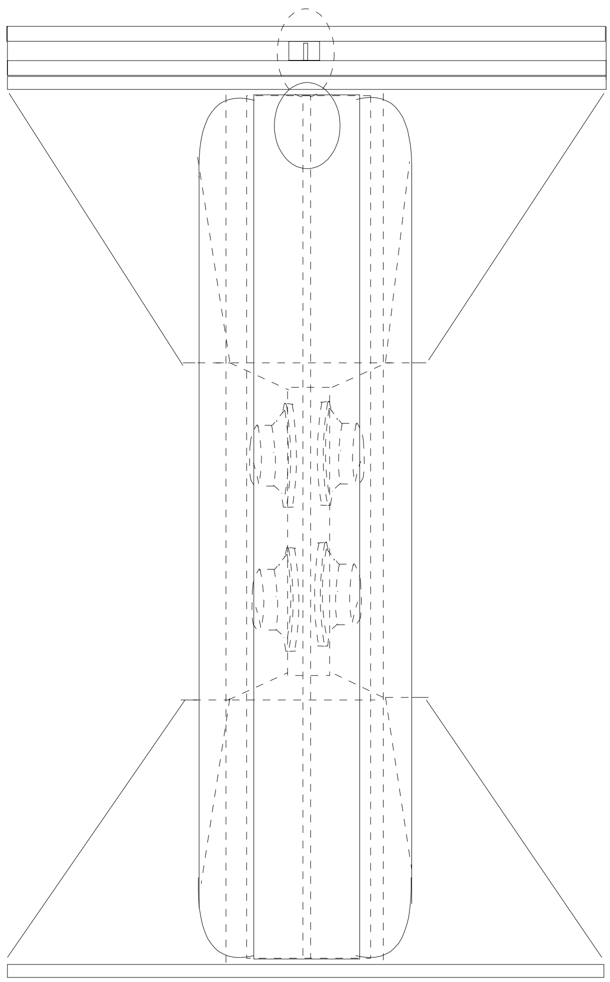


FIG. 9

Finishing the cabinet, for the prototype , was a simple paint job in an eggshell black acrylic. A budget finish with an acceptable appearance. Currently at the time of this paper, we are experimenting with some plastic 3 dimensional textured coatings, which are mar proof and hold their appearance under high stress conditions. We will be offering this cabinet in hand oiled oak, walnut, or rosewood veneer, with the high frequency horn out of solid hardwood to match.

The physical size is such that it will fit into a 24 x 24 x 48 inch box, and because the horn flare is left open in the back, it is easy for two men to handle and maneuver down narrow hallways and small doors. No assembly is required. Terminal cups are located on the front at the bottom of the cabinet for ease of access. Permanent installations may be re-wired out the back, or perhaps through the floor. High end speaker cable users will appreciate the front location.

SIGNAL PATH / FREQUENCY DIVISION

Internal wiring is done in balanced oxygen free copper wire which incorporates a stranded and solid conductor by Monster Cable (tm), so that high end speaker cable users will not loose the splendid detail so often lost in average speaker cabinet wiring and crossover networks. Wonder solder is used to join the low frequency driver(s) to the gold binding posts via the wire described.

Because of the extremely smooth frequency response of this horn, no crossover is used on the woofer, which also performs the duty of mid frequencies out to 4500 Hz. This is in reference to the *audiophile* configuration for homes, using one 6 inch driver. The high frequency unit consists of a 24 inch horn lens using a 1/2" compression driver crossed over at 12db around 4500Hz. The capacitors used are polypropylene, and are purchased in matched pairs to within 1/2 dB deviation. The inductors are a perfect lay air core of 16 gauge wire. The compression driver for the high frequency unit is wired with the polarity reversed for improved time alignment.

In the commercial alignment, the impedance drops to a low of 3.1 ohms, and there is a slight rise in efficiency between 250 to 450 Hz over the rest of the bandwidth. The four drivers are wired in series/parallel for a DC resistance of 7.1 ohms. Fig. 10 shows the crossovers used in both configurations. The bottom illustration is the crossover for the commercial alignment.

This crossover network consists of a balancing network to flatten out the rise in efficiency in the upper mid-bass range. There are three switches located on the front panel for adjustments.

Switch 1 - changes the inductor value from 7.0 to 3.5 Mh. Subjective result is an increase in the mid bass of about 3db.

Switch 2 - changes the circuit to run the woofers *DIRECT*, i.e. with no crossover. For use with active crossovers, and external custom networks. Subjective result is a thickening in the bass/mid bass.

Switch 3 - Bypass capacitor. Subjective results are an increase in midrange, treble.

In a two way wiring scheme as illustrated, flat response can be obtained by leaving switches 1 and 2 off, and turning switch 3 on. All three switches will effect the frequency balance of the horn, giving 9 possible combinations. In permanent commercial installations, the recommended wiring would be to bi-amp each horn using an active crossover, and possibly a parametric equalizer.

Fig. 11 shows the frequency response of both configurations. The high frequency horn has not been plotted here. The zero reference on both charts is 100 db.

EXPERIMENTAL RESULTS

Once this author completed the first horn, and rigged it with the 4 drivers, the initial listening tests were very promising. The low frequency response was tremendous. About 2 weeks later, the second horn was built and joined the first in our LAKE street listening room.[1] When the second cabinet was placed in the other room corner, it became a bass trap. Without hooking the second horn up, the first horn (left unit) was now void of any low bass response. When the second horn was hooked up, a
different phenomenon occurred.

Because of the original design intent, that would be a horn that works well in an average listening room, such as a living or family room, we proceeded with a retrofit to change the wave fronts so as to correct for anticipated standing wave problems in smaller square rooms. It was at this point that we selected a 6 inch driver and installed it into the front baffle of the horn. By using a low compliance, low Qts driver with a high Fs, we obtained fantastic results equaling or exceeding the original configuration. The efficiency of the horn dropped from 102 db 1w/1m, to 96.5 db 1w/1m. The power handling of the "home" configuration turned out to be quite good. 10 to 50 watts of amplification is quite impressive.

Because the pair of 6 inch drivers used had a base efficiency of 96.5db 1w/1m. We found that when using 200 watts per side RMS the intensity was such as to invoke fear. Running 250 watts per side still caused no audible distortion, and achieved a sound pressure level at the listening position 8 feet away of approximately 123 decibels. The result is simple testimony to the superior performance of this horn.

DISPERSION CHARACTERISTICS

This horn design was meant to create a life size interpretation of the real performance. The sound stage must be large, and the sound should be big. Having listened to a pair of KLIPSCHORNS for several weeks, and building audiophile towers with a hallmark for great imaging, I found very few similarities between the two. In fact, in a smaller listening room, I found the KLIPSCHORNS to be not terribly great at projecting a focused sound stage, and noticed walking about the room, that they tended to be a little beaming in the upper frequencies. I detected no low bass below 45 hz, and found the bass to be slightly thin sounding.

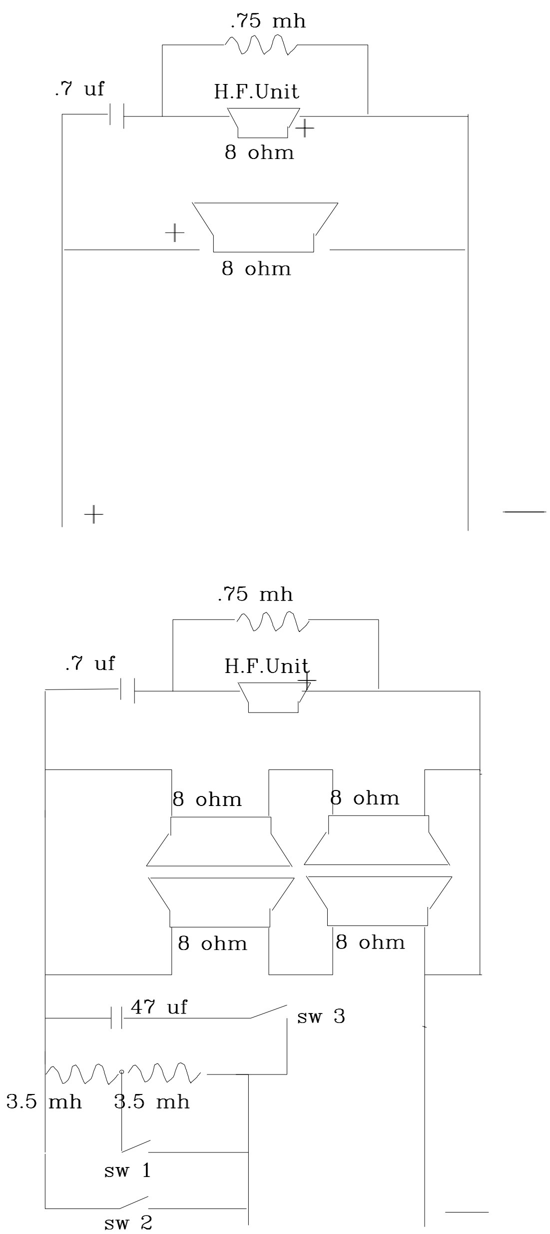
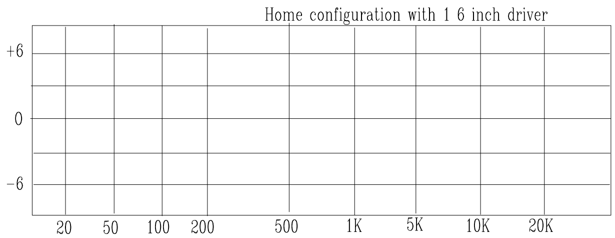


FIG 10



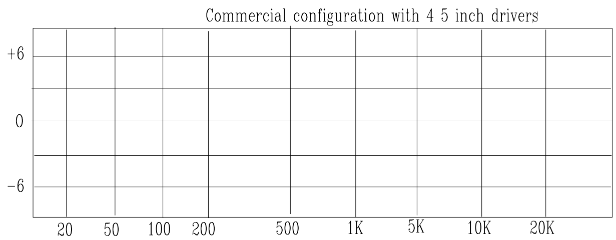


FIG. 11

The dispersion characteristics of our new horn are so improved , that this author found the sound stage and image focus to exceed his reference audiophile towers.

Listening tests conducted with my colleges, and associates, have resulted in 100% agreement that these are the best sounding horns they have ever heard. And from a performance standpoint, we think we have probably obtained a world record for the most output from a 6" diaphragm. These horns were personally voiced by this author to obtain a frequency balance that would appeal to the majority of those who listen to them.

NOTE:

These are the original 1994 white papers for the Decware Corner Horns. The author has built a single pair and listened to them using the single 6 inch driver configuration ever since. These papers will be amended as work continues once again in 2002.

The direction of work will be focused on the single driver configuration, with an efficiency that will mate well with low powered SET amps since it has been discovered by the author that these type of amplifiers have the best clarity and speed. At the time these papers were written no such intensions were evident. The original 6 inch drivers used in this project that have performed well will regular use for over 8 years are no longer available. Work is now in progress to mate this design with the popular LOWTHER drivers.