THE EDGAR MIDRANGE HORN

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"It remains hard to convince people, including acoustical engineers, that the midrange is where we live, and it is in the midrange that distortion is the most annoying and where amplitude response errors are most prominently evident. I have spent more man-hours of R & D time on the midrange than on the bass."[1]

Paul Klipsch, 1971

When I promised a midrange horn to go along with my 70Hz mini horn design (*SB* 2/83 p. 7), little did I realize how true Klipsch's words would be. In 1982 I had a midrange horn operating, but colorations in the sound quality were too objectionable to present to *SB* readers.

The colorations came from three main sources: driver limitations, throat and mouth configurations, and construction techniques and materials. In the process of researching, identifying and correcting each source of coloration, I found I was following the same path as many horn builders had followed over the last 60 years.

HORN HISTORY. When the radio boom hit the general public in the 1920's, a general need for sound amplification devices developed so that people weren't tied down with earphones. Since amplifiers were practically nonexistent, enterprising experimenters found that earphones could be fitted to phonograph horns to give the needed sound level in a room.

In one article[2] a pair of earphones was mounted in front of a wooden chopping bowl to give acoustic reinforcement. The "amplification" came from the resonant peaks in the horn response or, in the case of the chopping bowl, from cavity resonances. However, a horn does not "amplify"; it can only provide an efficient means for coupling the acoustic output from a small radiator to a free space.

The use of an earphone with a small permanent magnet only compounded the effects of inherent resonances in the old phonograph horns. Very often the use of a driver with a weak magnet introduces a nasty resonance at the lower end of the spectrum, even on an exponential horn. For a midrange horn with a resonance around 400-500Hz, such a peak gives a "horn like" nasal

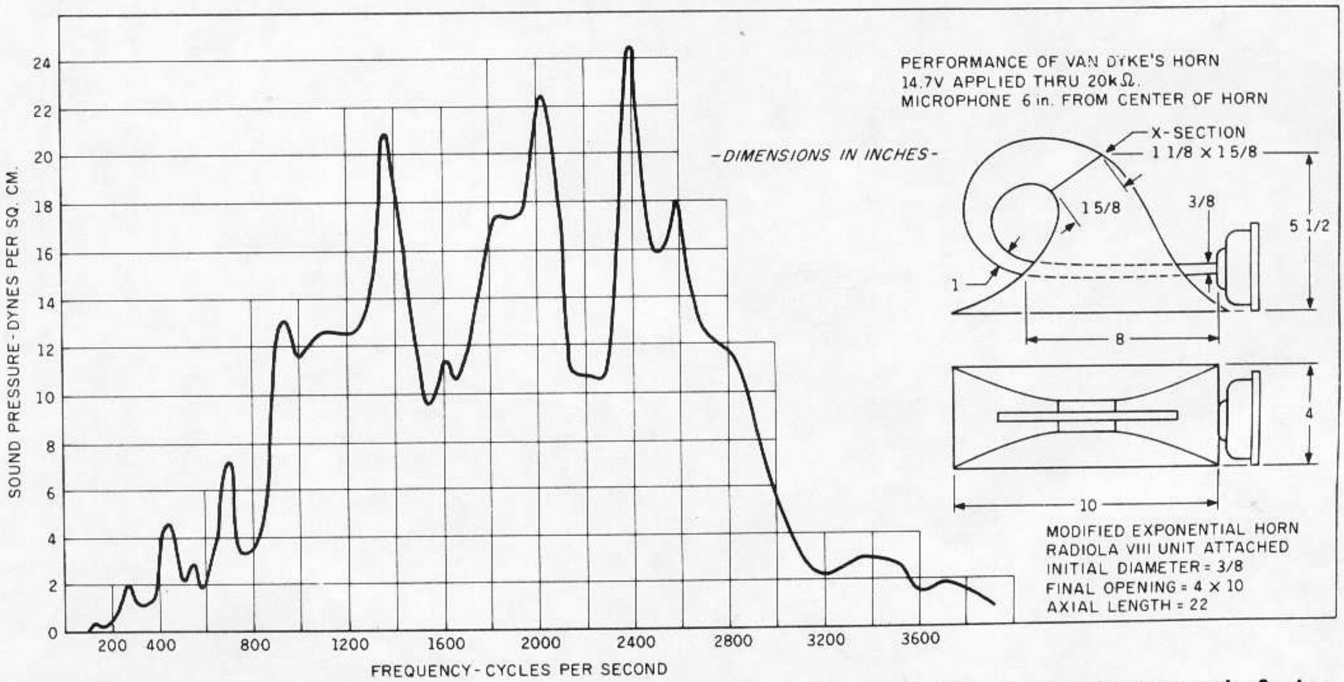

FIGURE 1a: The response of an experimental exponential horn (circa 1924) as measured by an RCA engineer. Notice the prominent response peaks. *Courtesy of the Smithsonian.*

sound quality that will make audiophiles shudder.

To give the reader a view of how those old horns sounded, *Fig. 1a* and *1b* are plots of the response of two sample horns as measured by an unknown RCA engineer in 1923 and 1924. I found these response graphs in the Smithsonian Museum archives through the aid of electro-acoustic devices curator Mr. Ed Sivowitch.

Figure 1a shows the response of a folded exponential horn with a series of three response peaks (peak to trough ratio of approximately 6dB) typical of an exponential horn with a too small mouth. In fact, from the given dimensions, the flare rate is 125Hz. The optimum mouth area should be 928 square inches; whereas the mouth area in this case is only 40 square inches. The Radiola driver probably has an effective response from only 1 to 3kHz, which implies that the designer failed to optimize the horn parameters to the driver capabilities.

The horn in *Fig. 1b* shows a decent response curve with a ripple of 3dB or less, ignoring the peak at the bottom of the spectrum. The initial peak is probably due to the effects of throat reactance and a weak magnet in the driver. Even though the horn in *Fig. 1b* has a much smoother response than the *Fig. 1a* horn, the sound quality would still be "tinny" due to the absence of frequencies below 500Hz.

It makes one wonder when you read the advertising hype of the period that told of the "wonderful realistic sound" that came from such horns. Of course, when wide range dynamic loudspeakers became available in the late 20s, the public quickly converted over to the new dynamics. The old gooseneck horns of that period are now prized as collector's items.

The reader may well ask, "Why look at these old response graphs made with antiquated measuring gear of dubious calibration standards?" The answer is horn acoustics have not changed in 60 years, and many of the same problems designers encountered in the 20s are still faced by horn builders today.

MID HORN SPECS. As I pointed out in my mini horn article, most bass horns have a mass cutoff in the 300-500Hz region. So a properly designed midrange horn should go down to a least 400Hz in order to mate with a bass horn.

A quick survey of commercial midrange horns available to the constructor shows that most have cutoffs of 600-800Hz. The reason for the higher cutoff frequencies is the market for midrange horns lies primarily with direct radiator woofers and not with bass horns. But if you have a bass horn, you still have a problem if you try to use one of these midrange horns due to a significant hole in the response around 500Hz. Some professional horns, i.e., JBL, with two inch diameter throats will go down to 500Hz, but they are expensive and really do not belong in a home environment.

My solution to the problem uses a midrange cone driver on a wooden midrange horn. This approach has been tried by several authors with varying success.[3,4,5]

The problems with this approach are manifold, as pointed out to me by reader R.J. Feeser.[6] Most cone drivers have too much mass to provide response above 1–2kHz, where they must mate to a tweeter horn. In addition, very complex interactions take place between cone stiffness, mass, size, the air chamber about the horn throat and the throat reactance, that can cause severe irregularities in the response. However, I felt with the profusion of midrange drivers on the market today, and with proper testing, I could find a few good candidates for a midrange horn.

TESTING DRIVERS. Over the years I have assembled a collection of oddball speakers, including several midrange drivers. Through the aid of a friend, who managed a local electronics store stocked with raw drivers, I was able to test a representative sample of midrange cone and dome drivers. The total collection, between my own and the store's contribution, was about 20. A sample illustrating the variety is shown in *Fig. 2*.

A number of years ago I was given a pair of Western Electric (WE) type 31 PA horns with two inch diameter throats, but minus the drivers. Since the proper drivers for these horns are expensive, the WE horns collected dust in my closet for several years. In fact, this midrange horn article was stimulated by my desire to find a proper driver for them. In the process the horns became a useful test stand for screening drivers.

I used an old Scott receiver (*Fig. 3*) as a white noise generator (i.e., interstation hiss although a GR noise generator was used in final testing) and amplifier. A Sennheiser MD421 microphone was poked into the mouth of the horn for a near field response test. I used an HP sweeping spectrum analyzer for the initial spectrum meas-

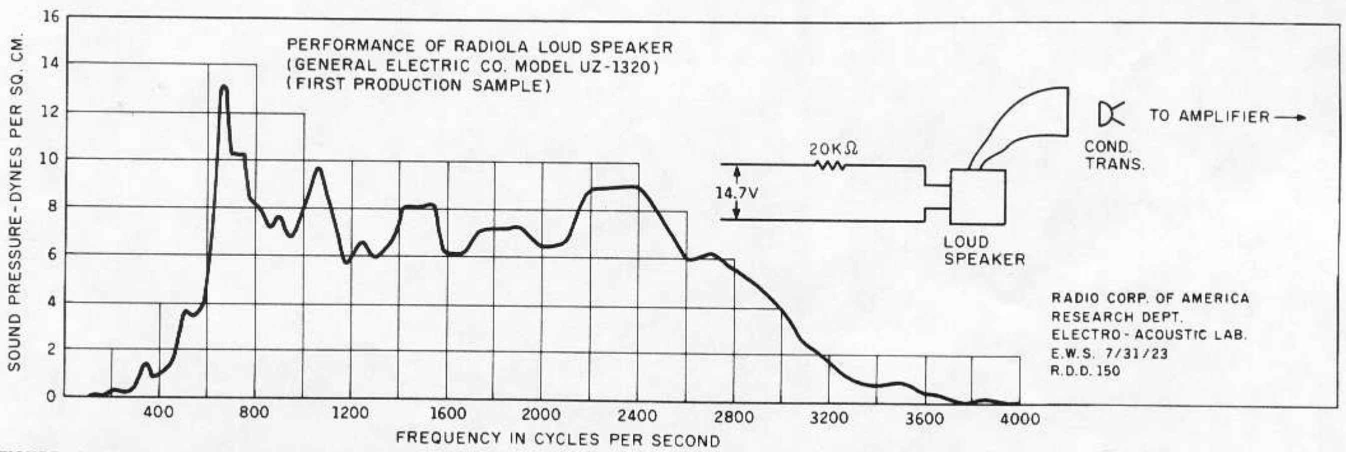

FIGURE 1b: The response of a midrange horn as measured by an RCA engineer (circa 1923). Other than the peak at the low end, the response is fairly smooth (less than 3dB ripple). *Courtesy of the Smithsonian.*

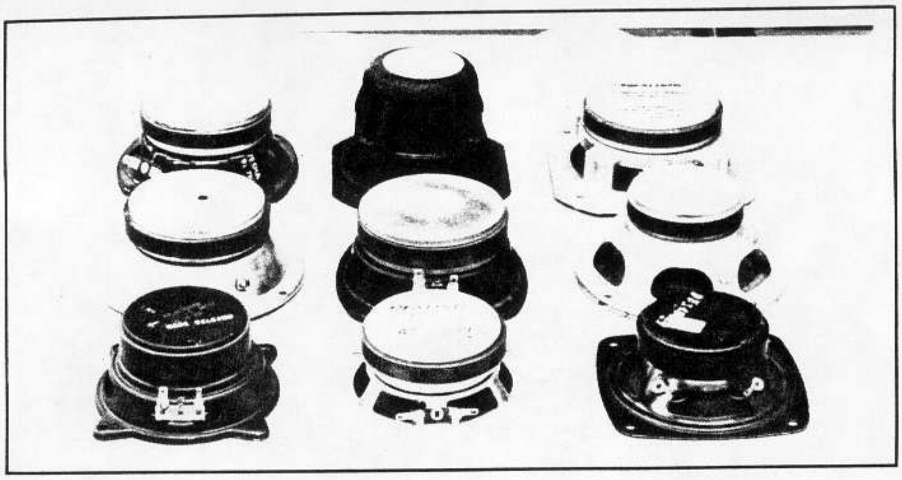

FIGURE 2: A sample of the drivers used in my initial tests.

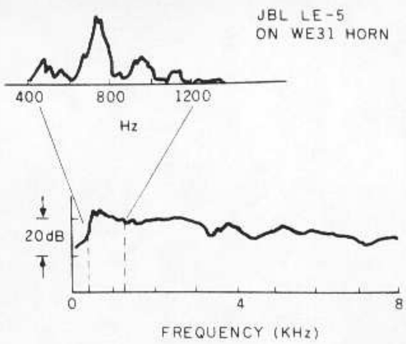

FIGURE 4: The spectrum response of a JBL LE-5 driver on the WE 31 horn. The blown up spectrum on a linear amplitude scale emphasizes the response peaks between 400 and 1200Hz.

urement, although later I substituted an FFT (Fast Fourier Transform) analyzer for greater resolution in the final tests.

I tried the WE horn with the 70Hz mini horn for a while with several drivers. My favorite driver was the JBL LE-5, a five-inch midrange cone driver that had long been the mainstay of the JBL speaker line. As a direct radiator midrange, it had a rising amplitude character with a frequency responsible for bright "west coast" sound. On a horn, the extended response of the LE-5 seemed to cancel out the natural tendency for the WE horn to attenuate the frequencies above 1kHz.

On many types of orchestral music the sound quality was outstanding, but when listening to a male announcer's voice on an FM station the midrange horn added an annoying distinct nasal quality to the sound. At the time I accepted it as something inherent in midrange horns as are their good qualities of increased dynamic range, lower distortion, etc.

When I first started white noise testing with the HP sweeping analyzer, I noticed an enhancement in the amplitude response around 500Hz with the WE horn. It was there with most drivers I tried, so I did not pay much attention to it. Later, with a time averaging FFT analyzer, the midrange enhancement resolved into distinct resonances, as shown in *Fig. 4*. Other drivers exhibited the same resonance structure so I began to question the design of this old WE horn as a suitable midrange horn design model.

OLSON'S CALCULATIONS. In the midst of my midrange horn quandary, a fellow scientist, Dave Rowe, walked into my office, introduced himself as a fellow speaker builder, and asked me to tell him all about horn loudspeakers. After some long discussions, he suggested that we take Olson's[7] horn acoustic impedance calculations and model the response variations of the various horns I had designed and built.

Acoustic impedance is defined as the ratio of the air particle pressure to the particle velocity. To most speaker builders this definition doesn't mean much. The following illustration may help.

If you place a tube of certain length over the front of a loudspeaker, you will notice the tube seems to reinforce certain frequencies. At these frequencies, determined by the length of the tube, a standing wave is created by the reflection of sound at the end of the tube. The speaker sees a high resistance of high acoustical impedance to work into at these resonant frequencies, and a low resistance in between. In a resonant horn, such as a trombone, the tube has a very slow taper until the horn's end flare, or bell. The rapid flare at the end creates a discontinuity or reflection point to create standing waves. A percentage of the sound energy leaks out and radiates as a musical note, while the rest remains in the standing wave inside the horn.

In contrast to resonant horns, a "transmission" horn, with an exponential, tractrix or conical flare, tries to minimize the reflections and match the high impedance a driver likes to see, to the low impedance of air. In a transmission horn the designer tries to minimize the ripple in the acoustic impedance, which the driver sees at the throat of the horn, and eliminate all resonant peaks (see Benade[8] for more discussion).

ACOUSTICAL IMPEDANCE. Olson gives the following expression for the

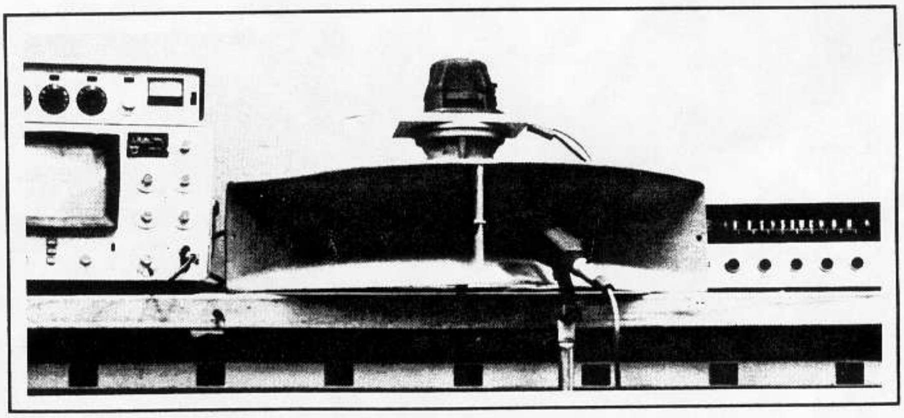

FIGURE 3: The initial test setup using a Western Electric Horn (Model 31), a HP sweeping analyzer, an old Scott receiver, a Shure microphone preamp and a Sennheiser MD-421 microphone.

acoustic impedance of a finite exponential horn:

$$Z_T = \frac{\rho C}{S_T}\left[\frac{S_m Z_m\,[\cos(bl+\theta)] + i\rho c\ \sin(bl)}{i\ S_m Z_m\ \sin(bl) + \rho c\ \cos(bl-\theta)}\right]$$

where:

S_T = area of throat
S_m = area of mouth
l = length of the horn
Z_T = acoustical impedance of throat
Z_m = acoustical impedance of mouth
a = $m/2$
b = $\frac{1}{2}\sqrt{4k^2-m^2}$
θ = $\tan^{-1} a/b$
k = $2\pi/\lambda$
m = $4\pi f_c/c$
f_c = flare cutoff frequency
c = speed of sound
ρ = density of air
f = frequency
λ = wave length
i = imaginary unit $=\sqrt{-1}$

For the mouth impedance, Olson approximates Z_m as the air load upon one side of a vibrating round piston set in an infinite wall. However most horn mouths are not round, but rectangular for practical reasons. For a rectangular mouth, we used the rectangular piston radiation impedance functions as tabulated by Burnett and Soroka.[9] They showed acoustical impedance to be a function of the aspect ratio of the sides. (If the rectangle has sides of length a and b, then the aspect ratio R = a/b, where a > b.)

As an experiment we simulated the throat reactance of the 1920s exponential horn in *Fig. 1a* and the WE 31 horn. Parameters of the WE horn were physically measured to be: flare rate = 250Hz, throat size = 2 inches diameter, mouth size 5 by 26 inches, and length = 16 inches.

Figure 5a shows the calculated acoustic impedance versus the measured response curve for the 1920s horn. The two response peaks below 800Hz do not correlate well with the acoustic impedance peaks. The higher frequency response peaks are probably due to resonances in the metal diaphragm of the driver. *Figure 5b* shows a similar comparison between the response curve and the calculated acoustic impedances for the WE horn.

By now the reader will agree with me that the old design method for midrange horns has many faults. The acoustic impedance calculations show

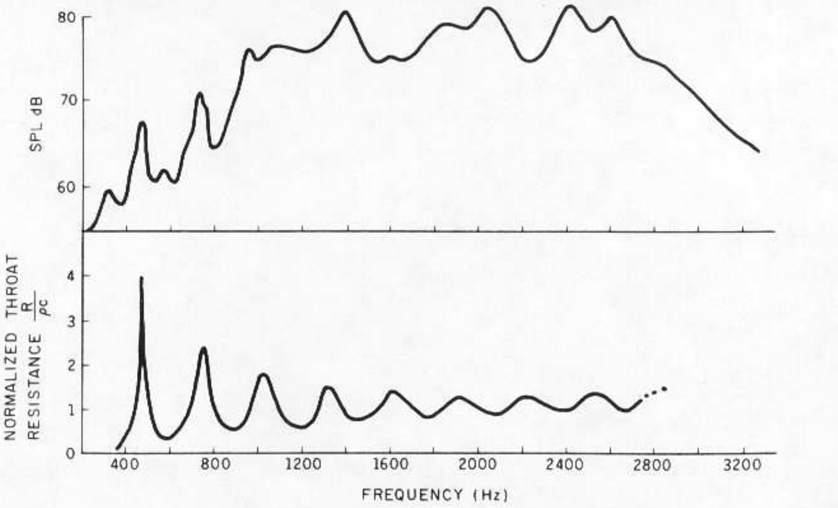

FIGURE 5a: The measured response of the old midrange horn of *Fig. 1a*, plotted on a log scale, compared with the calculated throat resistance.

they have many resonances that are unacceptable by today's standards. The basic problem arises when the flare rate frequency is set well below the mouth cutoff frequency, and the mouth is too narrow (i.e., high aspect ratio).

The latter fact is demonstrated by the calculations of *Fig. 6*. We take the case of a midrange horn with a 350Hz flare rate and mouth size, and vary the shape, keeping the mouth area constant. Four aspect ratios, R = 1, 2, 3 and 4 were used. The case of R = 2, (i.e., mouth width = twice the mouth height), appears to have the minimum ripple in the acoustic impedance.

TRACTRIX HORN DESIGN. When I wrote my paper on tractrix horn design (*SB* 2/81, p. 9), I must confess a certain *naivete* about horn design. It was pretty much magic to me as it was to many others.

The tractrix horn expansion was a case in point. Along with many others,

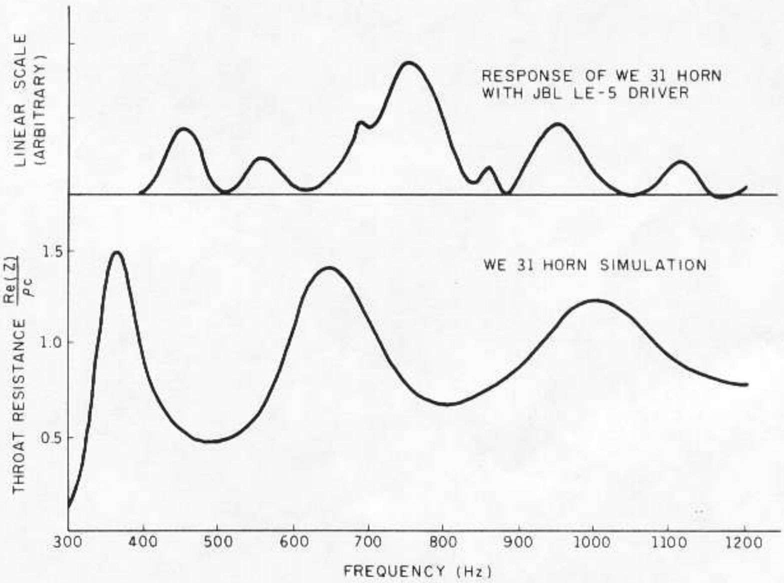

FIGURE 5b: A comparison of the measured response of the WE 31 horn, with the calculated throat resistance.

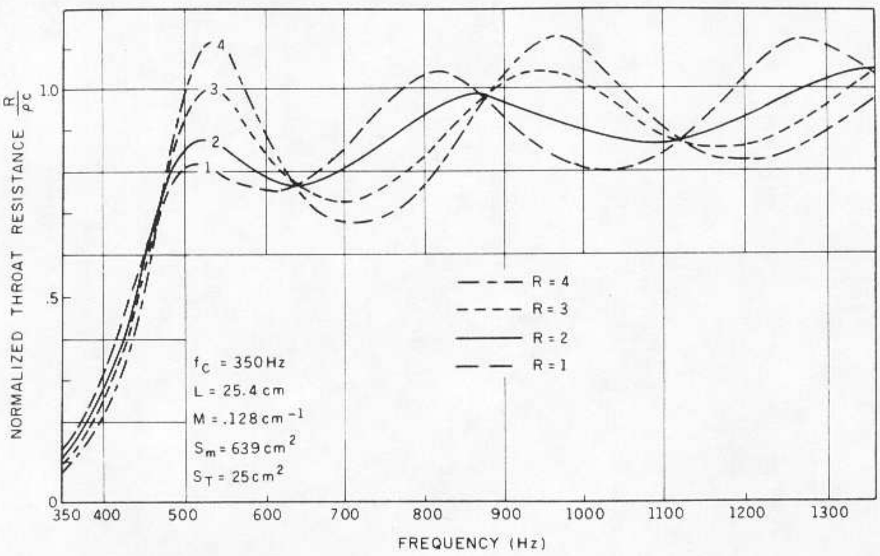

FIGURE 6: The effect of mouth shape on midrange horn throat resistance. R = 1 is a square mouth, and R = 4 is a long narrow mouth.

I thought that the horn shape was the key to everything. However, at this writing, a great many other factors, i.e., mouth shape, throat size and coupling and driver choice, have just as much bearing on achieving a good horn loudspeaker. Having said all this, the tractrix horn is still a good choice for midrange horns because it launches spherical waves that can yield excellent stereo imaging effects.

CONSTRUCTION. For our midrange horn I chose a 300Hz tractrix expansion, with a 9 by 18-inch mouth and 2 by 2-inch throat, that would mate with my JBL LE-5 driver. This gives a horn length of 10 inches. For construction I followed the suggestion of Babani[5] to make the horn top and bottom as a wedge shape, and to construct the curved sides with strips of wood.

To start construction of the form, laminate together with nails or screws several 9 by 10-inch pieces of plywood or particle board until the thickness is 2-inches. It can be done with two 1-inch plywood pieces, or one ½-inch and two ¾-inch plywood sections. Cut the edges off as shown in *Fig. 7*.

Mount this trapezoidal piece with screws on a 10 by 18-inch board, as shown in *Fig. 8*, to make the jig for the horn. The side rails help keep horn parts rigid while building the unit. To cut out the top and bottom pieces, first cut out a template as shown in *Fig. 9*.

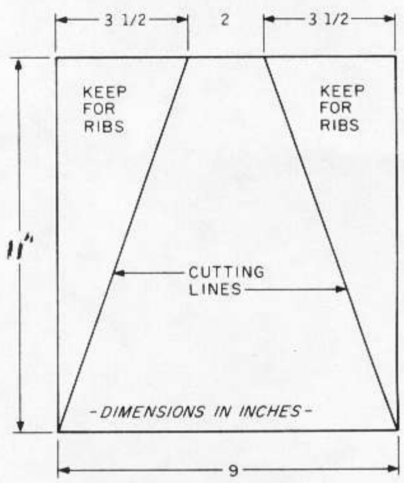

FIGURE 7: The cutout diagram for the trapezoidal form used in the horn jig. The form has to be 2 inches thick, and can be made from a sandwich with different thickness boards.

I plotted out the curve from *Table 1* on graph paper, with a 1 by 1-inch grid pattern that subdivides into 0.1-inch increments. With spray glue or rubber cement, mount the graph on a poster board or ⅛-inch masonite. Then cut out the template with a saber saw or an exacto knife. Take two 11½ by 18-inch pieces of ½-inch plywood or particle board, and nail them together with 1-inch brads. Place the template on the one side of the 11½ by 18-inch boards and trace out the tractrix curve.

TABLE 1

300Hz TRACTRIX EXPANSION

2″ x 2″ Throat x (inches)	9″ x 18″ Mouth W/2 inches
0	1.0
1	1.05
2	1.10
3	1.21
4	1.38
5	1.60
6	1.92
7	2.30
8	2.80
9	3.55
10	4.65
11	7.0
11.5	9.0

With a saber saw or a band saw cut out the curved horn section. If your saw balks at cutting out 1 inch thickness, then cut the two horn sections separately. By cutting the sections together, you obtain a symmetry of the two sides that accommodates any slight irregularities in sawing out the pattern.

I suggest you start a saw cut at the mouth. If you start from the throat, by the time you get to the narrow section of the mouth, the boards will tend to break off due to their own weight.

Separate the two curved sections and remove the brads. Place them on either side of the trapezoid form (as shown in *Fig. 10*) so they are properly centered. Attach them temporarily with a nail or screw to the trapezoid form so the nail or screw can be removed later.

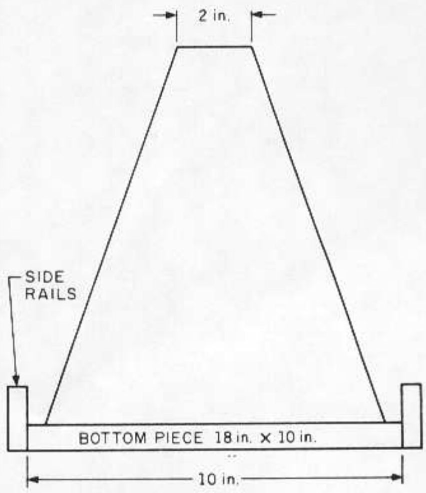

FIGURE 8: The trapezoidal form mounted on the jig. The bottom piece (18 by 10 inches) can be a ½ inch or greater in thickness.

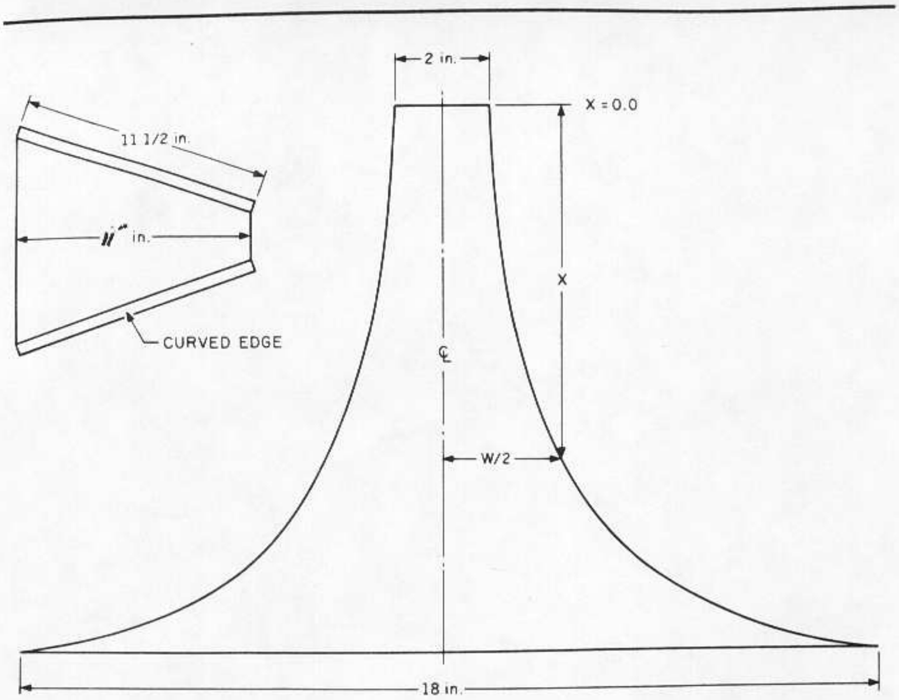

FIGURE 9: The scaled template for the top and bottom horn pieces. Plot *Table 1* on 1-inch grid engineering paper for a full size template.

Now rip a number of 1-inch (approximate) wide strips of ½-inch particle board. My strips are 1⅛ inches wide only because I found them in a scrap bin at a local woodshop (I'm a serious scrounger). Cut ten strips into 10 inch lengths. Place one across the curved sections so it straddles both. See that it touches the outside edge of the curved sections. Glue must be placed here for bonding. Spread a thick bead of carpenter's glue along the outside edge, starting at the mouth end and going up about 6 inches along the edge.

Place one of the 10-inch strips at the bottom, making sure the glue bonds between the strip and curved edge. Take another 10-inch strip, spread a bead of glue the length of the long edge where it comes in contact with the first strip. Repeat this process for five strips until it looks like *Fig. 11*.

Follow the same process for the other side. Let the glue set overnight, or for several hours. The reason for doing only five strips at the bottom is they tend to slide off the form if stacked up while the glue is wet. I have nailed the strips with brads, but the board tended to split or break off on the narrow curved end.

After the glue has set on the first strips, you can start cutting, fitting and gluing the succeeding strips until you reach the end of the throat. When the glue is dry on the rest of the strips, you may drive some 1-inch brads to add more strength. However, the structure is extremely rigid and non-resonant with only glue joints so that nailing is optional.

Remove the nails or screws that held the curved sections to the trapezoidal jig and lift off the horn. You may have to gently pry it off because sometimes glue will run down and stick the horn to the jig.

Looking into the horn you may notice some ⅛ inch gaps between the strips and the curved sections. I used Fixall or Water Putty to fill these. (Fixall is a coarse material and a fast drier. Water Putty is finer and takes longer to set.) After the gaps are filled, smooth off the excess filler with damp paper towels. Let the filler set and dry.

CONSTRUCTION TIPS. Some of you may ask, "Why can't I set my saber saw at the proper angle so the strips will be flat on the curved sections?" Well, if you notice after taking the horn off the jig, the gap between the strips and the curved section varies from being wide at the mouth to narrow at the throat, so there is no constant angle.

If you have access to a band saw, you can take a wedge (use one of the wedge cutoff pieces from making the jig) and mount it on one of the 9 by 18-inch rectangular pieces where the throat outline is drawn. When the tractrix curve is cut out, in the manner shown in *Fig. 12*, the correct angle is achieved along the curved section to allow flush mounting of the strips.

An alternative to using strips for constructing the curved side is to steam and bend wood. I tried this with ⅛-inch plywood (shown in *Fig. 13a*), but the thin walls have resonances (*Fig. 13b*) that show up in the response.

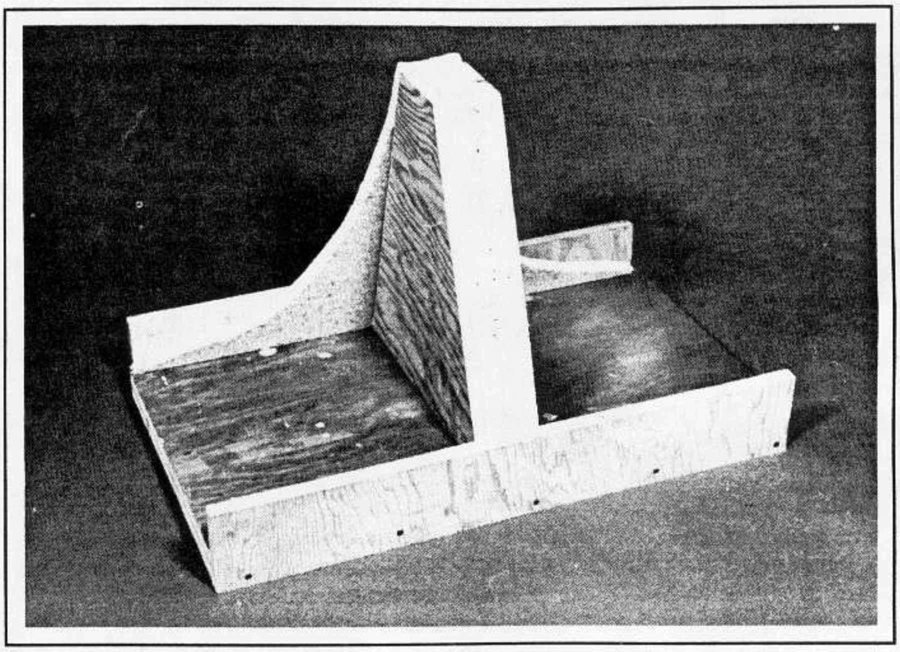

FIGURE 10: The horn jig with one top piece in place.

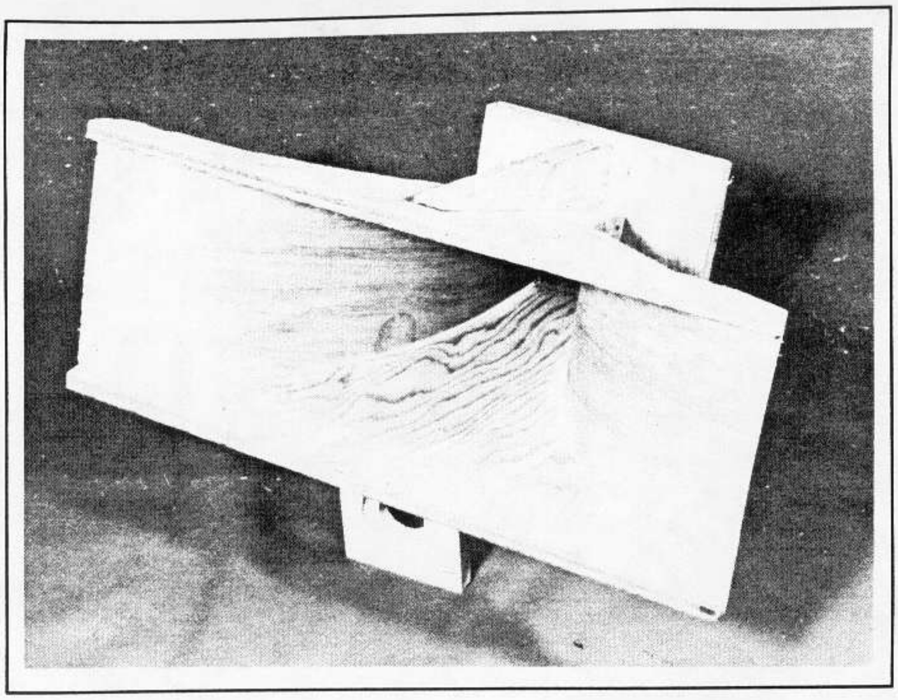

FIGURE 13a: An early experimental horn of mine with thin walls of ⅛-inch bent wood.

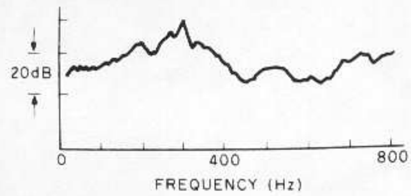

FIGURE 13b: The resonant nature of the thin wall horn produced by thumping the horn in front of a microphone. Notice the peak at 300Hz that will color sound.

Thicker plywood, ½ inch or greater, may give better results. But for the speaker builder with normal skills, the particle board strips are the easiest method.

FINISHING THE HORN. After the gaps have been filled, take a wood rasp or a Stanley Surform file and round off the corners of the 1-inch particle board strips where they join. Work off the excess material with rasps, files and sandpaper until you can run your hand over the curved surface and feel no bumps or joints. It's amazing how this relatively simple but labor intensive procedure can generate such a nice looking curve.

Now decide the thickness of your driver mounting plate. In my case, it depended on what scrap piece of ¾ or ½-inch plywood I had to give me a 10 by 10-inch square piece. Cut off the neck by the thickness of your mounting plate. I usually do not build up the strips on the curved side to the end of the throat, so that I can easily square off the throat's end with a belt sander.

Once the throat is faced off, take two of the end wedges left over from making the trapezoidal form. Center and glue them with clamps on the top and bottom flat sides to form the ribs (see *Fig. 14*). Now attach the speaker mounting board with screws to the ribs. I usually center the mounting board over the throat, then drill and drive in one screw. Then I place it on the side on which it normally rests in a system, and adjust the mounting board slightly so the whole assembly does not tip. Now you can drill and drive the other mounting screw.

Cut the throat opening next. With a pencil, mark the outline of the throat on the mounting board. Remove the mounting board. Center and draw a 2 by 2-inch square inside the throat outline. With a saber saw and wood rasp, cut out a 2 by 2-inch conical square throat opening on the speaker side, that matches with the throat opening on the other side.

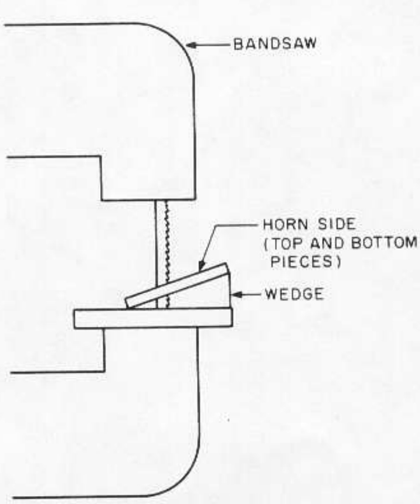

FIGURE 12: An alternative method for correctly cutting the beveled edges for the top and bottom pieces.

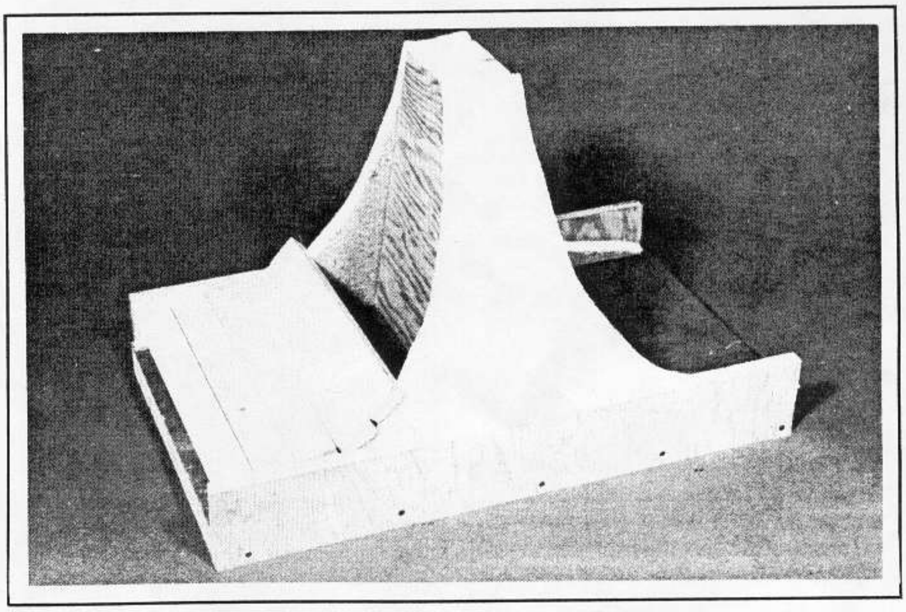

FIGURE 11: The initial placement of 1-inch wide strips to build up the horn's sides.

Now I could say you are finished, but the next problem is to match the speaker to the horn throat. The JBL LE-5 matched the tractrix horn with the 2 by 2-inch throat well, with a fairly flat frequency response from 400 to 4kHz as shown in *Fig. 15*. It also had a 105dB sensitivity at 1kHz (1W input measured with an Audioquest sound level meter at 1 meter away from the mouth), which is comparable to commercial horns.

Unfortunately, JBL no longer sells individual drivers from their commercial lines. But if you have a JBL 3-way system from the 1970s, it may have a usable LE-5. A possible improvement would be to make the tractrix horn, mount the LE-5 on it with an L-pad and hear an improvement in sound clarity and crispness.

AN ALTERNATE DRIVER. Because the JBL LE-5 was not available, I began to look at other candidates. The characteristics of the LE-5, which seemed to work well with horn loading, were a high BL factor and a small light cone. These characteristics give a radiation response which rises with frequency.

The first alternative candidate I found was a SIARE 16VR. It had a 40-ounce magnet and a 6-inch figberglass cone. However when I tried it on the horn with a 2 by 2-inch throat its frequency response, as shown in *Fig. 16*, was somewhat disappointing because of the 1.5kHz rolloff.

I concluded after some thought that the high frequency response could be improved if I used a larger throat to couple 1:1 to the cone size. When I sawed a length off the throat, as shown by *Fig. 17* and *19a*, the response improved to 3kHz. But a response peak at the low end appeared, as shown in *Fig. 18*.

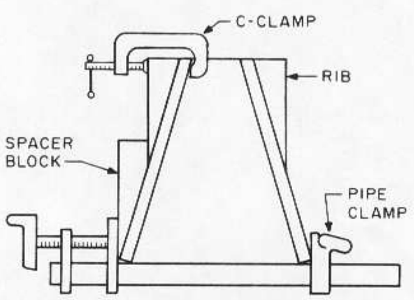

FIGURE 14: The clamp arrangement for mounting the ribs.

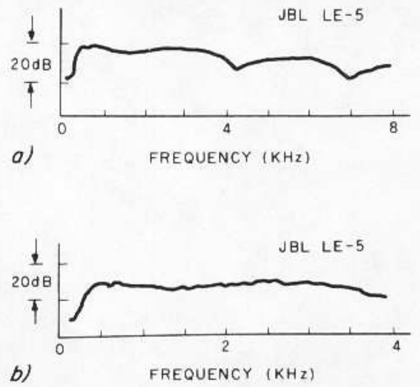

FIGURE 15: Response *(a)* is of a JBL LE-5 driver on 300Hz tractrix horn. Note the nulls at 4 and 7kHz. Response *(b)* is of *(a)* on an expanded scale.

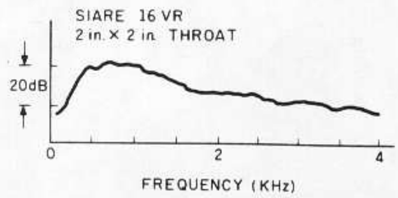

FIGURE 16: The response of an SIARE 16VR driver on a horn with 2 by 2-inch throat. Note the restricted response.

I accidentally found that if I introduced a gap in the throat-speaker interface, by offsetting the driver with ½-inch spacers (see *Fig. 19b*), the peak went away, as shown in *Fig. 20*. The gap's effect on the sound quality was very evident as the horn was lowered on the SIARE 16VR driver with white noise excitation. Without the gap the sound quality changes from an "open" sound to a "tunnelly" resonant quality.

The physics of going from a small throat to a large one are that phase cancellation occurs in the small throat, when sound paths to the throat from the cone are unequal. In compression driver horn systems, a phasing plug is used to solve this problem, but the complexity of a phase plug puts it out of reach for the amateur builder. By going to a larger throat, of a size comparable to the cone size, phase cancellation is reduced significantly. You will lose some efficiency, but I found the losses are small compared to the added octave of response gained.

The physics of the gap are that the gap behaves as a high pass filter, which effectively clips off the peak. The gap is equivalent to a short open tuning stub such as the one treated by Olson.

OTHER DRIVERS. I began to try other drivers that had the large BL factor and a rising radiation characteristic. The Polydax dome HD13D37 1¼-inch dome exhibited these characteristics. However, on a 2 by 2-inch throat horn it exhibited an annoying peak at 500Hz; but the rest of the response

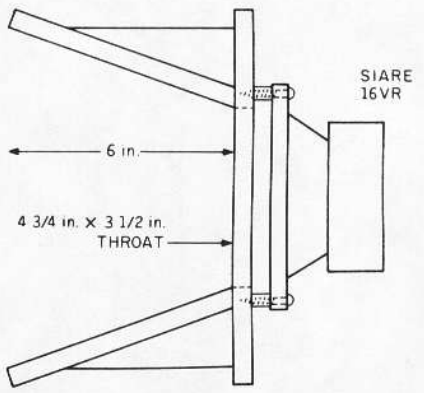

FIGURE 17: A shortened horn with a larger throat to match the SIARE 16VR driver.

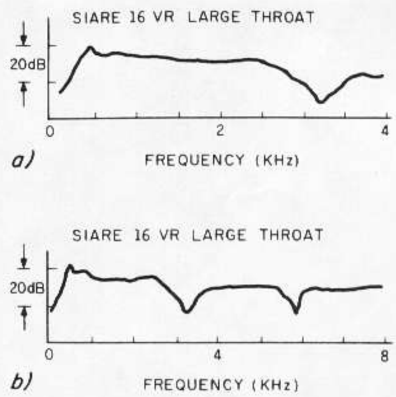

FIGURE 18: Response *(a)* is of an SIARE 16VR on a large throat horn. Note the response peak at the low end (500Hz). Response *(b)* is of *(a)* on an expanded scale. Note the nulls in the response are similar to those in *Fig. 15*.

Putting the Polydax dome on ½-inch standoffs helped somewhat, but filling was quite smooth and free from stricture, as shown in *Fig. 21a*. When I shortened the horn to a 4 by 2½-inch throat (7½ inches along the center axis), the response changed to a nice flat characteristic response of 4kHz, but a peak was still evident as demonstrated in *Fig. 21b*.

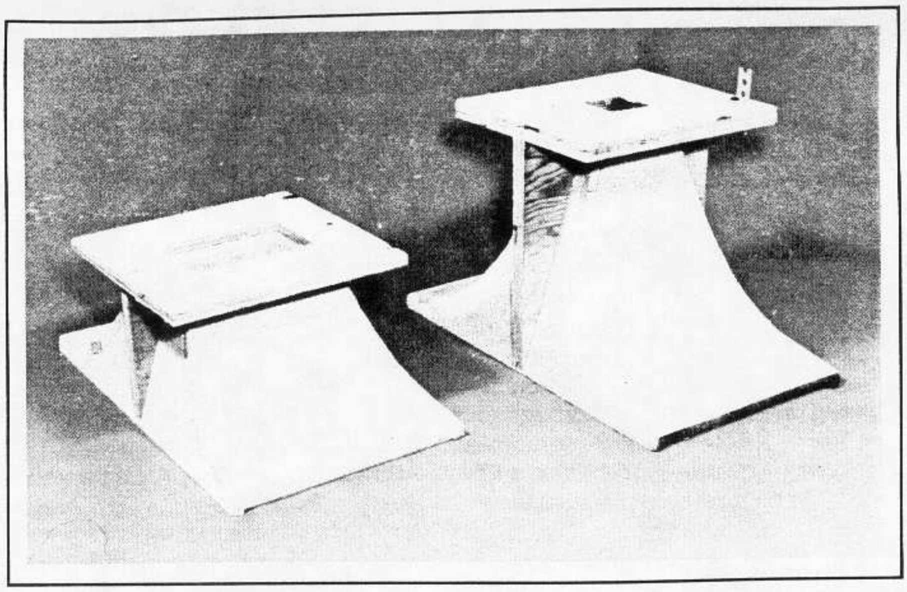

FIGURE 19a: A comparison of the two horns with differing throat sizes and horn lengths.

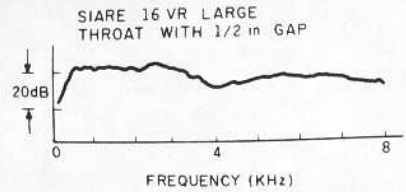

FIGURE 20: The response of an SIARE 16VR mounted on the shortened horns with ½-inch spacers. Notice the response has smoothed out from those in *Figs 16* and *18*.

the gap with ½-inch thick open-cell foam helped smooth out the response, as shown in *Fig. 21c*. I cut out a 1¾-inch diameter hole in the foam, to accommodate the dome and holes for the standoffs and mounting screws, as shown in the schematic *Fig. 22*. The foam acts as a resistive gap smoothing out the response above 3kHz and nicely extending it to 6kHz. The sensitivity is typically 100dB.

I found packing foam, typically found in shipping boxes, works the best. It is so porous you can hold it to your mouth and blow air through it. The foam, however, will deteriorate with time. I found using two layers of Scotchbrite® abrasive pads (found in hardware stores) will also work, and remain stable over time.

Searching the Polydax catalog, I found other driver candidates. One a 4-inch cone driver (HD12P25FSM) exhibited the best response (*Fig. 23*) on the same horn (4 by 2½-inch throat) as the Polydax dome, but with a ¼-inch gap and strips of Scotchbrite around the throat gap (but not covering the opening), it displayed 100dB sensitivity.

One person recommended the Polydax 6-inch professional midrange (PR17HR37TSM) used by several professional sound companies on their horns. *Figure 24a* plots the response on the large throat horn used with the SIARE 16VR. It shows the now familiar peak at 500Hz but, even worse, some irregular structure above 3kHz. Introducing a ½-inch gap at the throat, with foam strips around the edge, smooths out the response as shown in *Fig. 24b*.

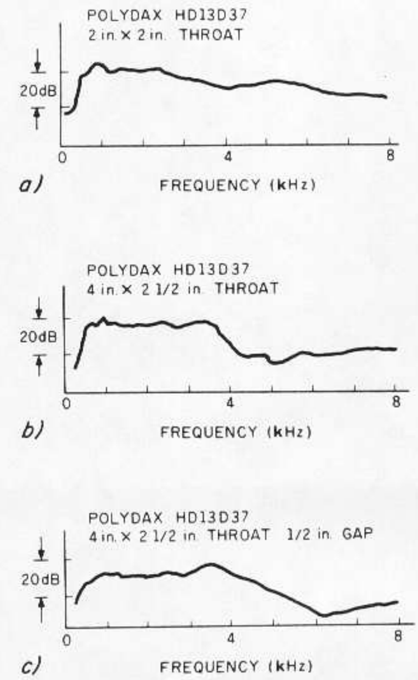

FIGURE 21: Response *(a)* is of a Polydax HD13D37 dome on a tractrix horn with a 2 by 2-inch throat. The response has an annoying peak below 1kHz. Response *(b)* is of a Polydax dome on the midsize throat tractrix horn. The response peak, although reduced, remains. Response *(c)*is of a Polydax dome with a ½-inch gap at the throat filled with porous foam rubber. The response is smoothed.

As I was trying to wrap up this article, I received a catalog from Focal Loudspeakers that described a number of drivers with possibilities for horn loading. Of the four models I tried, one 7-inch model (7N303) gave a very flat response (one of the best I've seen so far) on the large throat horn with about 100dB sensitivity. It also has some possible midbass horn applications with a resonant frequency of 70Hz.

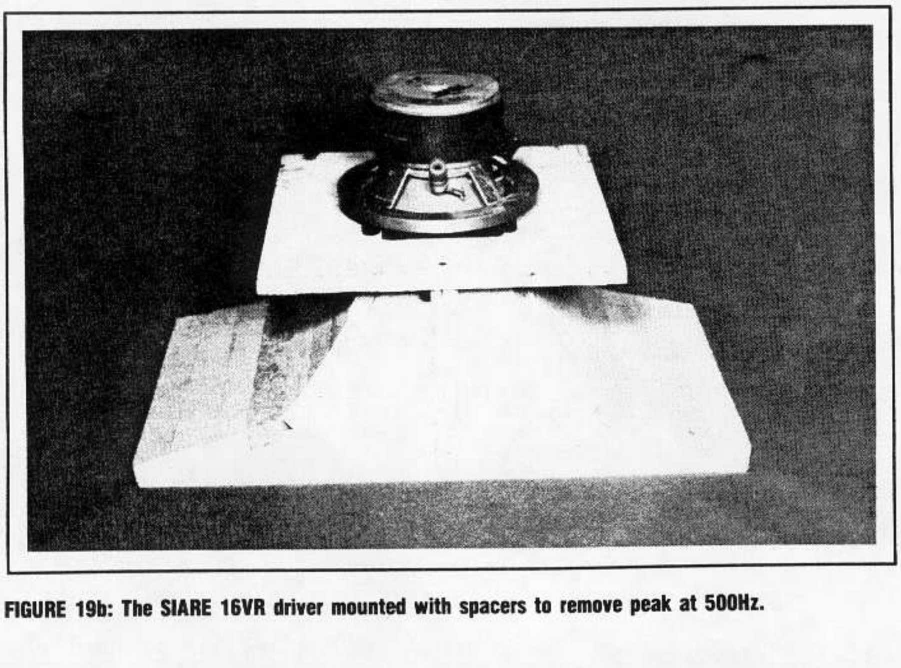

FIGURE 19b: The SIARE 16VR driver mounted with spacers to remove peak at 500Hz.

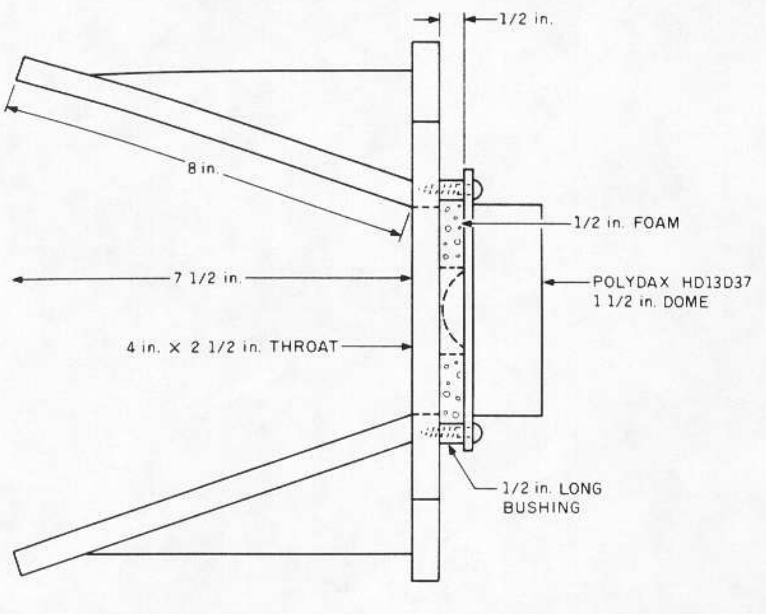

FIGURE 22: A cut away of the midsize tractrix horn with the Polydax dome driver.

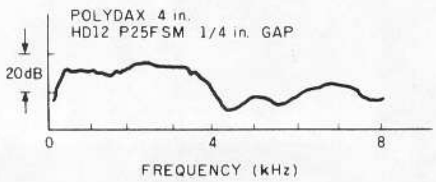

FIGURE 23: The response of the Polydax HD12P25FSM 4-inch driver on the tractrix horn with a ¼-inch gap at the throat and the gap edges filled with foam.

A NEW THEORY. In the classical theory of horns the upper mass cutoff ($2f_s/Q_{es}$) usually defines the effective upper frequency range. For example, in the case of the LE-5, I measure a Q_{es} of 2.74 and f_s of 316Hz, which would mean an upper mass cutoff of 230Hz, obviously well below our 4kHz measured response. I did not understand what was going on until I interviewed Ted Jordan (*SB* 2/84) and heard his ideas of suspension control of diaphragms.

Jordan,[10] and others who design full-range speakers, rely on stiffness and damping of the suspension to extend the high frequency response of the driver. This stiffness will overcome the control of the cone mass upon the power radiated from the speaker. Suspension control also gives a rising radiation characteristic, which eventually rolls off at some upper frequency, where the mass of the cone begins to exert influence.

A horn loads a driver by replacing the characteristic radiation resistance of a direct radiation (proportional to f^2, where f is frequency) by a constant radiation resistance determined by horn parameters. This phenomenon is schematically shown in *Fig. 26*, where the rising portion of a piston's radiation resistance is replaced by the horn's higher radiation resistance.

The mathematics of this phenomenon are somewhat complex, as dem-

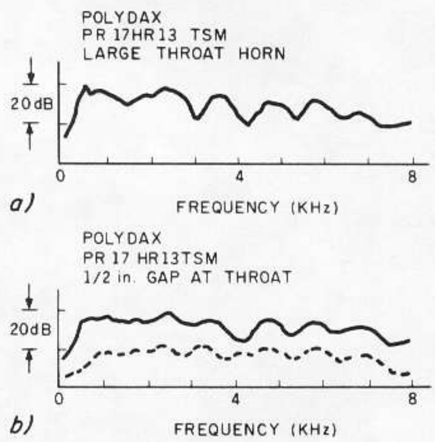

FIGURE 24: Response *(a)* is of a Polydax PR17HP37TSM 6-inch driver on the large throat horn. Response *(b)* is the same driver with a 1-inch gap at the throat stuffed with foam at the edges. The free air space response is shown for comparison.

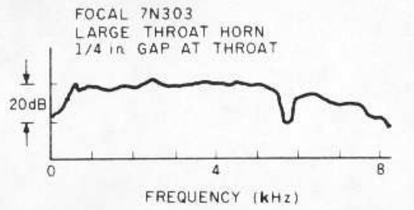

FIGURE 25: The response of a Focal 7N303 7-inch driver on a large throat horn with a ¼-inch gap at the throat.

onstrated by Brociner[11], and I have yet to fit it all together. But, as demonstrated here, it will suffice to say cone drivers can and do work on large throat horns with good efficiency and frequency range.

MATCHING OTHER SPEAKERS. With closed box speakers the sensitivity of most components, (i.e., woofers, midranges and tweeters), usually ranges around 90dB. However, the sensitivity of horn systems can range from 100 to 110dB; so some attention must be paid to the proper integration of midrange horns, with horn and closed box systems.

Any of the midrange horns described earlier can be used with a closed box system. However, the midrange driver must be attenuated by an L-pad to bring it down to the level of the closed box woofer. Usually this attenuation is on the order of 10 to 15dB. I have used several of the midrange horns, with both sealed box and bass reflex systems, and midrange detailing from the horn significantly increases the resolution and imaging qualities of the total system. It pays to move the tweeter driver back so it is in proper alignment in regard to time with the midrange driver. When this modification is made female singing voices usually change from a rough character to a smooth blend.

In horn systems it is usually best to select a midrange horn with the same sensitivity level as the bass horn. If the bass horn is rated at 105dB, use one of the 105dB driver midrange horn combinations. For the Klipschorn, my midrange horn size should fit in the top volume for the mid and tweeter horns, although you may have to enlarge the cutout for the mouth. The Klipschorn is usually rated at 104dB sensitivity, so a good choice is one of the 105dB rated horns with some slight attenuation.

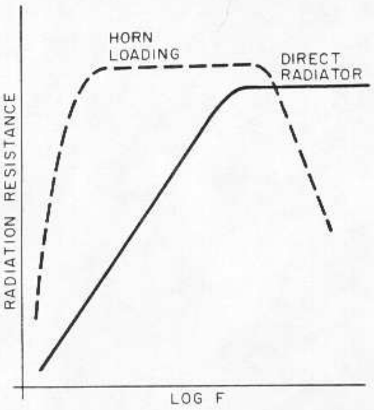

FIGURE 26: The radiation resistance of a direct radiator versus that for horn loading.

Some readers may have noticed I did not use back chambers on the open back drivers. I did experiment with back chambers and found the box sizes were usually comparable to the half or quarter wavelengths, at some midrange frequency, so either resonances or nulls would show up in the response.

If you do place the midrange horn in the Klipschorn, isolate the back with fiberglass insulation. If you isolate the speaker with a closed back, make it as large as possible and stuff it with fiberglass insulation or other good absorbent material. However, the best response is usually obtained with the back open because the drivers are suspension dominated and don't need a restoring force from an air chamber.

CONCLUSIONS. Although this midrange horn construction project may seem out of the mainstream for some speaker builders, it offers a new and different path for upgrading your old horn system or closed box system. Most of the comments I have received from listeners are on the clarity and crispness of the sound. The transient detail of the violin bowing or guitar pick is evident without harshness.

I think it is also evident from this article that one can easily build a bad-sounding midrange horn system. In the literature you will not find any discussion of horn mouth shape influence on sound quality. Although some large PA horns with square or similar mouths are on the market, most of the horns available to the speaker builder have wide narrow mouths that may lead to a peaky response.

The route I have shown for a good horn design is to choose a rectangular mouth (2:1 aspect ratio), or a square mouth, and a mouth size frequency cutoff equal to the flare rate frequency. Deviations from this design philosophy will introduce peaks in the response.

The most important ingredient in this approach is good driver selection. You may have noticed that I mentioned only drivers that work well with horn loading (see *Table 2*). If I listed the ones that do not work with horns, this article would run on for several more pages, because most drivers are designed as direct radiators, not horn drivers. However, I have shown that a small group of drivers, with larger than normal magnets and with stiffness control of the diaphragm, work well with horn loading. With stiff diaphragm drivers a throat size equal to or slightly larger than the driver will give the most extended range. Also a gap at the throat, either left open or stuffed with foam, will tame resonances at the low end and remove the "horn like" sound coloration.

This article has taken a number of years to assemble and digest the research results, and I think the wait has been worthwhile. It has been a labor of love with countless evenings and weekends spent with numerous drivers and horns in front of a spectrum analyzer. So for all the horn enthusiasts out there, I give you the *Edgar Midrange Horn*.

TABLE 2

DRIVER	PRICE CLASS	HORN	RESPONSE	SENSITIVITY
JBL LE5	$60 (used)	Long	400–4kHz	105dB
SIARE 16VR	$60	Short	400–4kHz	105dB
Polydax HD13D37	$20	Mid	400–5kHz	100dB
Polydax HD12P25FSM	$20	Mid	400–4kHz	100dB
Polydax PR17HR37TSM	$40	Short	400–4kHz	105dB
Focal 7N303	$60	Short	400–5.5kHz	100dB

Note: Any horn (less driver), as built by the author, may be purchased at a cost of $60. Contact: Bruce Edgar, Box 1515, Redondo Beach, CA 90278, or use Fast Reply # FI16 for more information.

ACKNOWLEDGEMENTS

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