speakers

TLAH: Transmission Line Array Horn

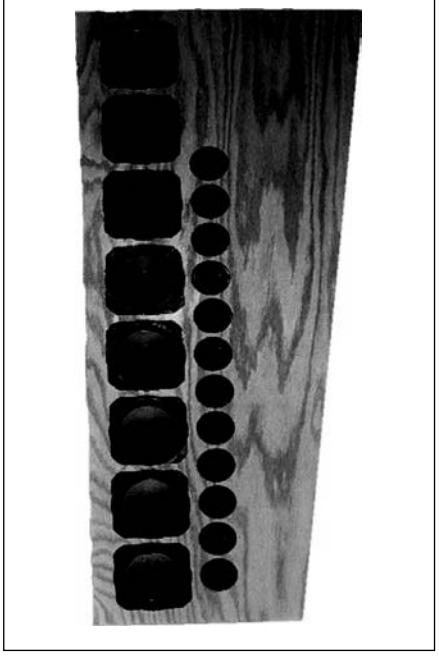
By Bill Fitzmaurice

Back

A dozen tweeters and eight mid-woofers complement the author's horn sub—for a total package that delivers a really big sound.

PHOTO 1: THE TLAH PAIR IN MY LIVING ROOM. IT APPEARS QUITE NARROW, BUT 3′ FROM THE REAR WALL THE ROOM EXPANDS TO THE LEFT ANOTHER 7′.

PHOTO 2: THE COMPLETED TLAH.



For quite some time now, many of you have been asking me to design another high-efficiency speaker for hi-fi/home theater use, and I've promised to do so as soon as my schedule allowed. I don't know when that would have been except for the good folks at Parts Express, who offered a deal that I couldn't pass up. Last winter they sold me wide-range 4″ mid-woofers at the silly price of only 87 cents apiece. I didn't know what I was going to do with them, but that price was too good to believe, so I ordered 16 of them. The shipping was going to cost better than half what the drivers would, so to fatten the order a bit I also ordered two dozen closeout ⅜″ dome tweeters, which at 32 cents apiece cost less than the price of a six-pack.

The two boxes full of drivers sat in my basement through the winter and spring, and even after I opened my workshop for the season they remained uncrated, as I still needed to do the final revisions on my Tuba 18 sub (a*X* Jan. '05). When completed, the Tuba 18 prototype ended up in my living room, and it wasn't there a full day before I realized that the high-sensitivity folded-horn sub was making the rest of my system sound, well, rather small. My MTM satellites just weren't in the same league as the Tuba. I knew that I needed to come up with a high-sensitivity replacement for them, and then my thoughts returned to the 40 drivers sitting idle in the basement. The answer to what to do with them was obvious: line array.

LINE 'EM UP

Line arrays are a natural for high sensitivity, since you achieve an additional 6dB of voltage sensitivity over a single driver with every doubling of the number of drivers. I figured that eight Chinese generic mid-woofers per side—rated perhaps optimistically at 87dB/2.83V—should deliver at least 95dB. That would be at 4Ω, but my amp would not find that a problem. The Japanese tweeters claimed a similar sensitivity, so surely a dozen of them per side (rated at 6Ω) would prove formidable. I could wire them as four parallel sets of three tweeters apiece in series, for a 4.5Ω load.

The mid-woofers would work fine in a sealed or vented box, but because the line array demanded an oblong cabinet shape, another option seemed logical: transmission line. Normally a TL is energized by a driver or two toward one end of the pipe, and I had no way of knowing whether it would work with drivers along the full length of the line. But if it didn't I could always seal the end of the box or toss in a duct. The driver Qts of 0.77 and Fs of 105Hz meshed pretty well with the idea of a 100Hz TL, because the best results in a TL are usually obtained when the driver Fs is close to the line quarter-wavelength frequency and Qts is as close as possible to 1.0 (something to

keep in mind when shopping for your own bargain-basement specials).

A quarter-wave tube for 100Hz would measure 34″ long, sufficient to house the eight fours, though I added a couple of extra inches for good measure. I wanted to use a tapered line and to tilt the cabinet downward somewhat, because my living room demanded a high mounting position. These two requirements meshed by placing the larger end of the line at the top. This also meant that the line exit would be nearly a quarter-wavelength from the ceiling at 100Hz, and if I wasn't careful the resulting Allison effect could negate a lot of its bass output.

FIGURE 1: CABINET BOTTOM (TEMPORARY).

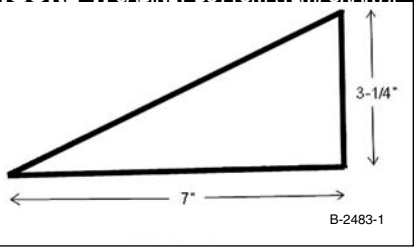
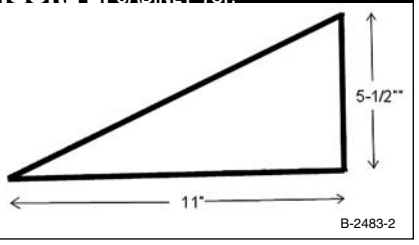


FIGURE 2: CABINET TOP.



PLACEMENT

Log on to almost any Internet audio forum and you'll find an inordinate number of posts dedicated to proper speaker placement. There are even computer programs devoted to curing placement woes, though a basic understanding of quarter-wavelength cancellation and half-wavelength augmentation is all you really require. My intended location put the line exit 40″ from the ceiling, which would invite a cancellation node just below the Fp of the TL. I decided to use corner placement to give a boost in the bottom end to help counter this. To enhance the corner placement aspect, and actually introduce a bit of horn loading to the vent output, I made the cabinets triangular.

This also put the cabinets in a naturally toed-in position, while seamlessly melding the baffle with the room walls to eliminate the baffle diffraction step. The resulting conglomeration is a hybrid of three different speaker types; I call it the TLAH, for Transmission Line Array Horn (*Photo 1*).

There are a few points to remember about line arrays. The first is that you must keep the drivers tightly packed, especially the tweeters. A line array sums the outputs of the point sources within it into a single coherent wave front, but only when the distance between the various radiating planes is less than a

FIGURE 3: TLAH BOTTOM VIEW.

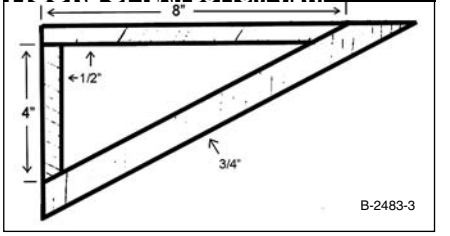
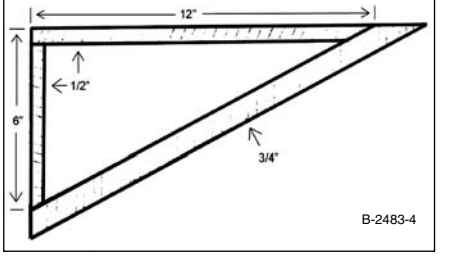


FIGURE 4: TLAH TOP VIEW.



wavelength. Even when the frames are touching, this requirement can be problematic at, say, 13kHz, where a wavelength is only an inch, and typical dome tweeter driver frames are 2″ wide. For this reason, continuous ribbon planars are preferred for line arrays.

The closeout tweeters I used were flangeless, originally intended for coax mounting on an autosound woofer, resulting in less than a 2″ gap between their domes. Closer would have been better, but they proved adequate. When choosing your tweeters, find some that will allow minimal spacing (*Photo 2*). The same caveat applies to the mid-woofers, though you'll find that many in the applicable 3–4″ size have semi-square "pincushion" frames like my closeouts, which makes close placement easy. If you get mid-woofers with round frames, it would be best if they practically touch each other.

As far as the 6dB increase in voltage sensitivity with doubling of drivers is concerned, that aspect is frequency limited; as you add drivers, the increase in sensitivity is nonlinear and there is a rolloff at the upper end. This is somewhat ameliorated by another facet of the line array, which is the near-field/far-field transition. Within the near-field, SPL drops at 3dB per doubling of distance from the source, going to 6dB when the far-field transition frequency has been reached. That frequency, and the distance from the source at which the transition occurs, is dependent on the height of the array according to the formula $r = l^2 f/700$, where l is the array height and r and l are expressed in meters.

In the case of the TLAH, with a tweeter array height of 0.6 meters, the transition at 12kHz takes place about 6 meters out, while the transition at 1kHz for the 0.8 meter high mid-woofer array occurs at less than a meter out. Therefore, at the typical listening position, the high-frequency rolloff is offset to some extent by the near-field condition of those same high frequencies.

With the tweeter and mid-woofer lines side-by-each, there is potential for comb filtering on the horizontal plane near the crossover frequency where the outputs overlap in frequency. Minimize that with a 3rd-order or higher crossover, along with placement of the two lines physically as tight as is practical. Stuffing the line with polyfill is also required to eliminate resonance. While there are formulas on how much stuffing is required, I didn't use them. I found that using enough polyester pillow filling to thoroughly stuff the line without compressing the material worked just fine.

CONSTRUCTION

Construction of the TLAH is relatively simple, though the acute angles at the cabinet edges are a bit tricky. I built the prototype with a baffle made of oak-veneer ¾″ plywood, with the remaining parts made of ½″ plywood. You could

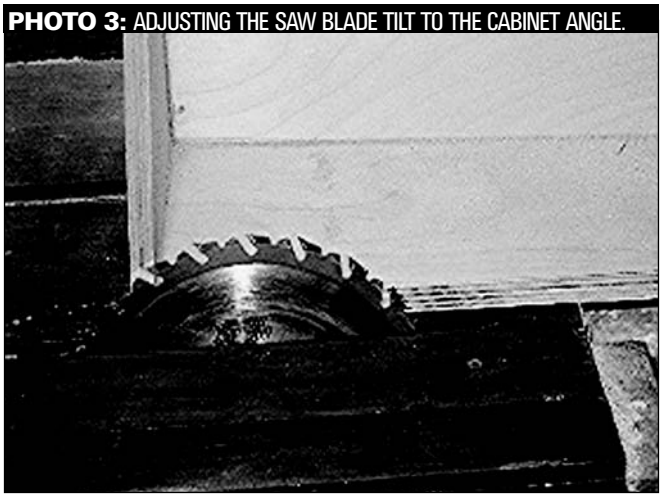


PHOTO 3: ADJUSTING THE SAW BLADE TILT TO THE CABINET ANGLE.

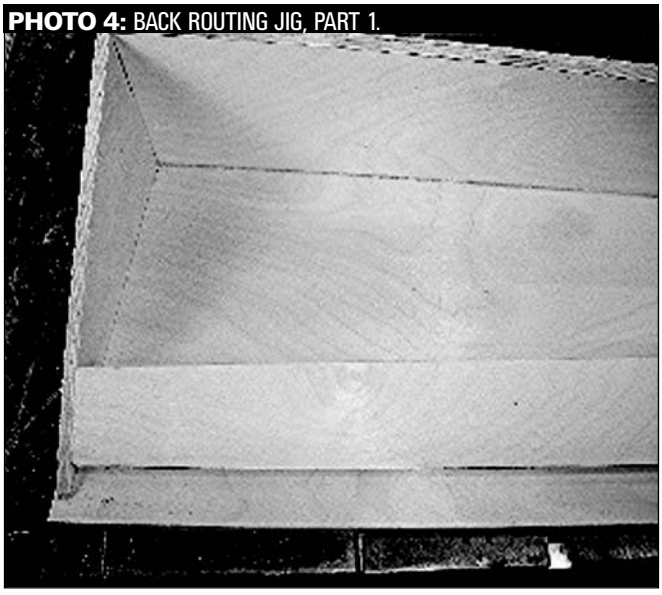


PHOTO 4: BACK ROUTING JIG, PART 1.

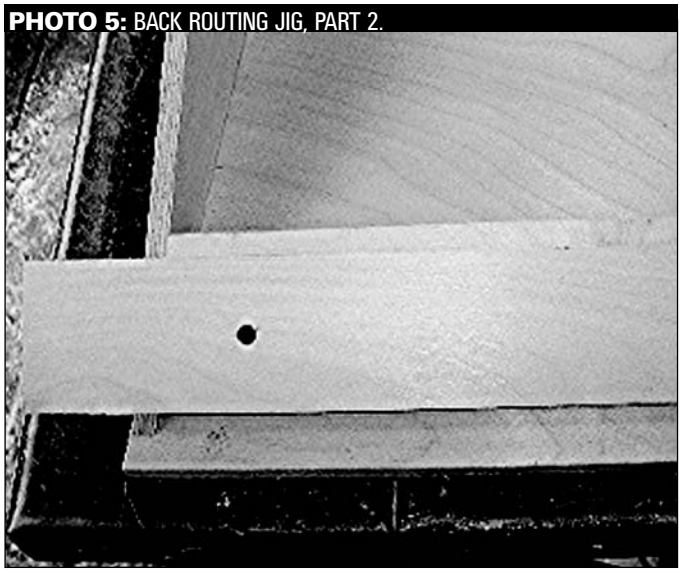


PHOTO 5: BACK ROUTING JIG, PART 2.

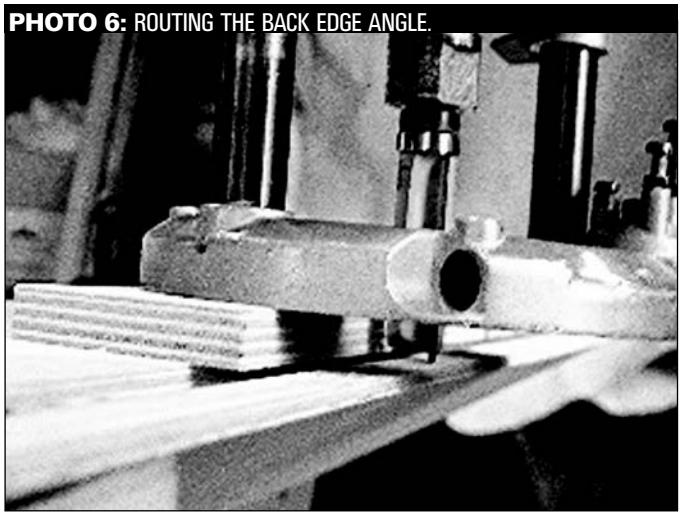
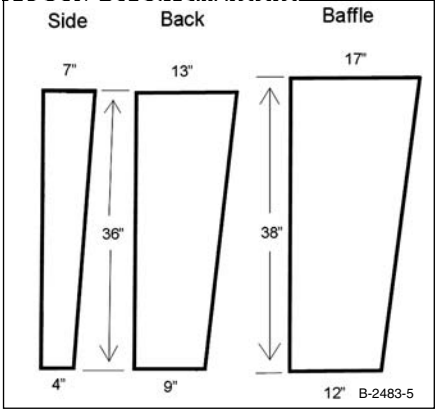


PHOTO 6: ROUTING THE BACK EDGE ANGLE.

also use either particleboard or MDF. As usual, you should glue and screw joints, but there is very little acoustic pressure inside this box, so "built like a tank" construction techniques are not warranted.

These boxes are mirror-imaged twins, so it's best to build them simultaneously to keep track of the left and right halves of the pair. The first step is to cut out the tops and bottoms (*Figs. 1* and *2*). You can see how they interface with the other parts in *Figs. 3* and *4*. The bottoms are temporary construction aids only, so be sure not to use any adhesive on them. Next cut out the backs and sides (*Fig. 5*), leaving them oversized to allow plenty of selvages for trimming. Each set is jointed to each other first and then to their respective top and bottom (no glue on the bottom!).

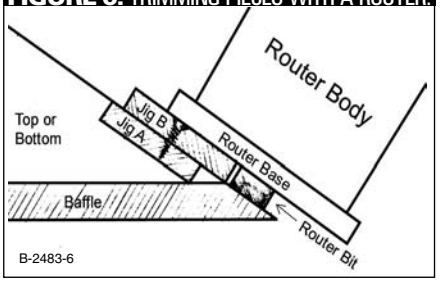
FIGURE 5: BOX DIMENSIONS.



The next step is to trim the back and side to the same angle as the top and bottom. It's easy to just draw a line on the inside of the side from the top to the bottom, set a table-saw blade to the correct angle by matching it to the angle of the top and bottom (*Photo 3*), and cut away. However, you can't use the same procedure on the back, because the angle is too severe for the blade to adjust to it. It is possible to duplicate the procedure used on the side by using a very high (6″ or more) rip fence and running the assembly across the saw with the back against the fence. But an easy alternative is to use the router.

Screw a jig of scrap plywood from the top to the bottom, with the plywood just touching the back. Add a second piece of plywood over the first, which will serve as a platform for the router base to rest on (*Photos 4*, *5*, and *Fig. 6*). Now run the router across the platform to trim the back edge to the proper angle,

FIGURE 6: TRIMMING PIECES WITH A ROUTER.

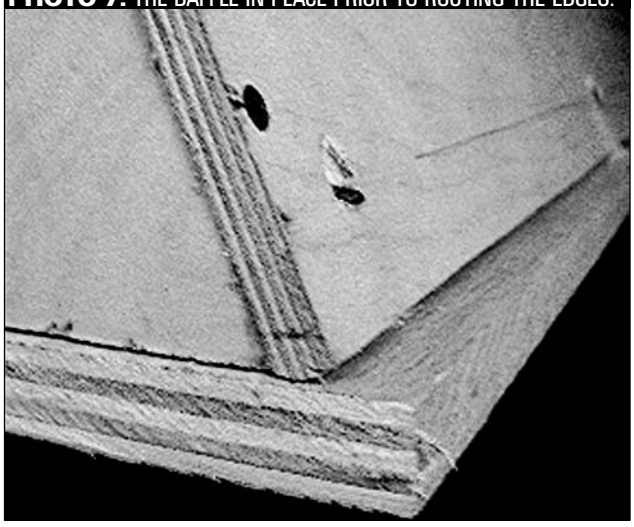


doing so with multiple passes in small increments (*Photo 6*). To be sure that the work piece is stable during the routing procedure, clamp or screw it to the work bench; if you use screws, fill the holes in the cabinet after you're done.

Cut out the baffles according to *Fig. 5*. Note that they are a couple of inches longer than the rest of the box, to allow an overhang of an inch at either end. Temporarily attach them to the assemblies, using countersunk drywall screws driven from the rear (*Photo 7*).

Trim the baffle edges to the correct angles, this time using the platform and router technique on both edges; cutting the baffle with the front side down on the table saw would chip the face. If you don't have a router, you must mark

PHOTO 7: THE BAFFLE IN PLACE PRIOR TO ROUTING THE EDGES.



the baffle where the cut lines go and remove it from the assembly so that you can saw it with the face up.

With so many driver holes to cut in the baffle, you probably should invest in a pair of hole-saws. Draw the centerline of the mid-woofers 3½″ from the side edge, and space the drivers as close as practical to each other. Start marking the mid-woofer locations at the top of the box, so that any leftover baffle area is at the bottom. Mark the centerline for the tweeters as close as you can to the woofers, and the tweeters as close to each other as possible, with the lowermost tweeter horizontally on-center with the lowermost mid-woofer. After cutting all the holes, sand the face smooth and apply your finish; add veneer and finish it at this time if you aren't using pre-veneered plywood.

DRIVER INSTALLATION

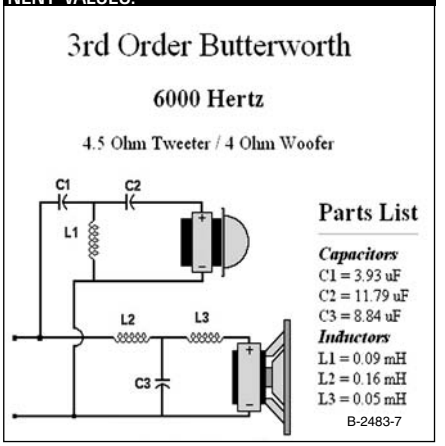
When the finish is dry, mount the drivers. With small pincushion-style mid-woofers there could be issues with gasketing the flange; I used silicone caulk to seal them from the rear. Likewise, mounting frameless tweeters calls for a special technique. I cut the mounting holes ⅛″ oversize, wrapped foam weather-stripping around the tweeters to hold them in place, and then again glued them from the rear with silicone caulk. You could also use masking tape to hold the tweeters in position while gluing. The crossover components are also glued to the inside of the baffle, with either hot-melt glue or silicone caulk (*Photo 8*).

As previously noted, you should use at least a 3rd-order crossover. I use an interactive website to find basic crossover component values; the address is http://www.lalena.com/audio/calculator/xover/. For my drivers the site gave the values shown in *Fig. 7*. After initial testing, the frequency response was quite adequate, so I didn't alter the circuit. You must consider the driver wiring scheme before buying your drivers.

With eight 8Ω mid-woofers, I wired them as series pairs, with the four pairs then paralleled for a 4Ω load. If your amp demands an 8Ω load, you may use either 4Ω or 16Ω drivers, or you may use nine 8Ω drivers wired as series/parallel "triplets," making the box a few inches longer to accommodate the extra driver. Keep in mind that with the high system sensitivity even 4Ω load won't pull a lot of current at normal listening levels. My 6Ω tweeters allowed me to use 12 drivers wired as four paralleled sets of three, with each set of three series wired, for a 4.5Ω load. You'll need to figure in advance how to wire your tweeters and how many to use to arrive at a load very close to that of the mid-woofers. If that results in a projected SPL higher than that of the mid-woofers, all the better, for reasons to be seen later.

After you have installed and wired the drivers, drill a hole through the cabinet top for the speaker wire, or alternately install a set of binding posts; in either case make sure the top is sealed airtight. Remove the temporary bottom from the box assembly and weather-strip the box edges

FIGURE 7: OBTAINING CROSSOVER COMPONENT VALUES.



where the baffle will mate; you don't want to glue the baffle in place in case you ever need to replace any drivers. Fill the box with sufficient polyester pillow stuffing to thoroughly stuff the box, but not so much that it requires a lot of force to compress it when the baffle is placed over the box. Reattach the baffle with screws and attach wall hanging hardware to the back as required. *C'est fini*.

As far as the mounting scheme goes, you aren't restricted to the suggested corner placement. For the reason why, look at *Fig. 8*, which shows a very respectable response from 100Hz. I measured this with the cabinet freestanding outdoors, so you could use the box in a freestanding mode indoors with some sort of stand to raise it to proper height. That height is determined by the tweeters, keeping in mind that the array has a very narrow vertical dispersion. I recommend that you have the listening position on-axis with at least the topmost or bottommost tweeter in the array—somewhere in the middle is even better. If you must mount the boxes high as I did, the downward tilt of the box helps.

FIGURE 8: SPL CHART.

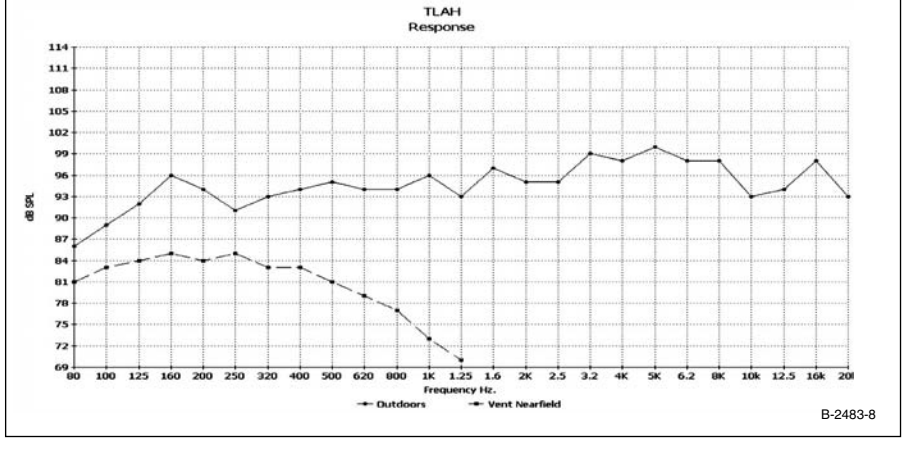
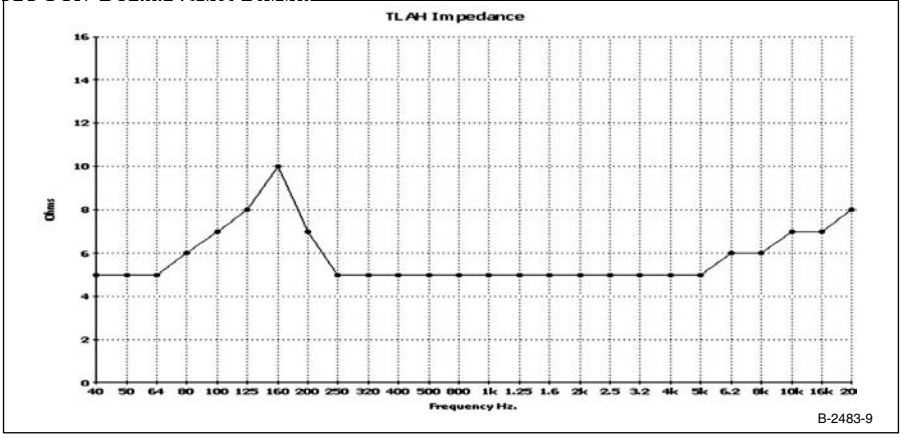


FIGURE 9: IMPEDANCE CHART.



MEASUREMENTS

Figure 8 reflects a freestanding outdoor measurement, and does not consider the effects of corner placement, the horn loading of the vent output, and the elimination of the baffle step, all of which contribute considerably to sensitivity. These enhancements also are mostly in the low end, so with corner placement you can expect an average SPL of about 99dB, with a decided tilt in favor of the bass. For that reason, having the base tweeter sensitivity a few dB higher than that of the mid-woofers is not a bad idea.

The final caveat applies to the vent output, which gives a goodly percentage of the bass. You need to avoid Allison effect cancellation from both the ceiling and floor reflections, which at 100Hz would occur at a distance of about 2.8′. If you cross the box over at the minimum recommended 80Hz, you must be sure that both the ceiling and floor are more than 3.5′ from the vent, which means your ceiling will need to be over 7′ high.

Speaking of the vent, the lower trace on the SPL chart shows the vent output, scaled downward for clarity. The vent response goes quite a bit higher in frequency than would be seen from a normally loaded TL, which is to be expected with the lower drivers so close to the vent. This begs the question about whether the box qualifies as a true TL, and that is answered by *Fig. 9*.

STUFFING

One of the hallmarks of a TL is an impedance sweep with a single low-frequency bump, in the same fashion as a sealed box. You can see that there is indeed a single bump at 160Hz, with exceedingly flat impedance across the rest of the bandwidth that, along with the very flat response, also shows that the stuffing density is adequate. To be sure that your TL is adequately stuffed, run an impedance sweep looking for additional peaks. With adequate stuffing, high-frequency resonant nodes are eliminated and only the single peak remains.

While *Fig. 9* confirms that this box is a real TL, the frequency of the response bump is about a half-octave higher than the line quarter-wavelength frequency and driver Fs, where ideally it would be much closer. I attribute this to the fact that the lower drivers are so close to the line exit that they really aren't being loaded by it, causing an upward shift in the system resonant frequency. This is confirmed by the falling response of the line exit below 160Hz, but as that shortcoming of the design is countered in use by boundary loading, it isn't problematic. I found that my TLAHs integrate just fine with my sub with an 80Hz crossover.

SPL and impedance charts aside, the main question remains: How do they sound? The best term I can think of is "Big." Really big. Yes, their sensitivity allows them to keep up with my Tuba 18 sub, and they will play cleanly to levels well beyond what the WAF (wife acceptance factor) will allow, but moreover they just sound different.

LISTENING

To my ear they sound like a very good set of horns. I believe that the physically large wave front produced by the line is akin to the large wave front produced by the mouth of a horn. I wouldn't hesitate to recommend the design to anyone who's wanted the sound that until now you really needed a horn to get.

The other night my spouse and I watched "The Lord of The Rings: Return of the King" at peak levels over 115dB, and it sounded so good that even she didn't complain. Yet, they take up only a quarter of the space that a 100Hz horn would, and there's also the factor of cost. Mine cost a total of about 60 bucks complete for the drivers, cabinets, and crossovers. That's $60 for the pair. Your cost will vary, of course, depending on what is available on close-out, but even at ten times the price these speakers would still be a bargain. ***aX***

PHOTO 8: REAR VIEW OF THE BAFFLE WITH DRIVERS AND CROSSOVER IN PLACE.

FIGURE 10: TLAH WIRING DIAGRAM.